RESEARCH AND TECHNOLOGY

ANNUAL REPORT 1980

George C. Marshall Space Flight Center

Research and Technology Office

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INTRODUCTION

The Marshall Space Flight Center continued its many and varied research and technology projects during Fiscal Year 1980. These projects, sponsored by the Offices of Space Science, Space Transportation Systems, Aeronautics and Space Technology, and Space and Terrestrial Applications, respectively, are laying an essential foundation of knowledge and capability to support future programs. A dedicated cadre of research personnel, together with a management philosophy of providing a beneficial environment for research and technology activities, ensure that the objectives of the many tasks are being attained.

In addition, there have been a number of actions taken to upgrade the physical plant and facilities of the Center, such as establishment of the Space Environmental Effects Facility (by the Office of Aeronautics and Space Technology) and the combining and improvement of the Center's simulation facilities. Also, an active association with local and regional universities allows research personnel to keep abreast of the latest developments in the academic community.

The results presented in this report are the more significant of the fiscal year. They are, necessarily, abbreviated. More information can be obtained, either through the Research and Technology Office or by contacting the individual identified with each task in the report. Additional copies of this report may be obtained from the Research and Technology Office, (Correspondence Code ER01/Telephone FTS 872-1023 or Commercial AC 205-453-1023), MSFC, AL 35812.

SOLAR-TERRESTRIAL PHYSICS

Research this year yielded significant discoveries about the nature of the solar-terrestrial environment. The Solar Maximum Mission provided new knowledge of the processes which initiate and sustain solar flares and has shed new light on the massive ejection of solar matter which occurs during transient coronal events. Both processes result in an impulsive perturbation of the solar-terrestrial system, causing changes in the Earth's atmosphere and magnetosphere. The basic solar output has also been found to vary by one-tenth of a percent, a magnitude which would have significant climatic implications on the Earth.

Nearer Earth, the geospace environment was found to consist of a mixing bowl of ionized gas or plasma originating in the Sun-Earth system. Direct measurements from the International Sun/Earth Explorer (ISEE) spacecraft and the Spacecraft Charging at High Altitude (SCATHA) satellite are unveiling surprising new information on the Earth's plasma environment, including hints about the multiple sources of the plasma and the variety of processes which accelerate the plasma and control its dynamics. Studies of the Earth's magnetosphere are being applied to the study of planetary environments, such as the probing of Jupiter and its interaction with its moons.
(E. A. Tandberg Hanssen/ES51/205-453-0027)

SOLAR PHYSICS

Solar Maximum Mission

This year was the Solar Maximum Year (SMY), an international science program to study the Sun, and which involves the coordination of space-borne and ground-based observations of solar activity. MSFC contributed importantly to the SMY program through its magnetograph facility observations and its Ultraviolet Spectrometer and Polarimeter (UVSP) experiment on the Solar Maximum Mission. Initial UVSP results are giving new information on flare build-up processes. In February 1980, NASA successfully launched a scientific satellite whose mission is to study the Sun during a period in the sunspot cycle when solar activity is at a maximum. The Solar Maximum Mission (SMM) spacecraft contains seven different scientific instruments for studying the Sun in different wavelength regions. MSFC's UVSP experiment is obtaining information about the solar atmosphere in ultraviolet light. This part of the electromagnetic spectrum allows study of the transition zone between the Sun's lower atmosphere, the chromosphere, and its upper atmosphere, the corona. The addition of a rotating polarizer in the optical train of this instrument also allows measurement of the polarization of the light. From an analysis of these measurements scientists are able to determine characteristics of the solar magnetic field.

The instrument does not view the entire Sun but only about one-fifteenth of the solar surface at one time. This field of view is sufficient to study the sunspot regions and activity centers where the turbulent solar activity occurs. Figure 1 is a photograph made from

the data of the UVSP experiment sent by the satellite to ground tracking stations. This photograph of the SW limb of the Sun on March 27, 1980, shows the loop structure of solar prominences as seen in the ultraviolet light at 1548 Å, primarily from light emitted by carbon ions in the solar atmosphere. These loop structures are part of an activity center and outline the containment of plasma at different temperatures by the stronger magnetic field associated with this active region.

Figure 1. Photograph of UVSP Data, March 27, 1980, Showing Loop Structure of Solar Prominences.

Preliminary scientific results obtained from the data during the first 3 months of operation concerning three different studies in solar physics are of particular significance: (1) measurement of the line-of-sight component of the magnetic field in the transition region, indicating a substantial radial magnetic field fairly high above a sunspot; (2) measurement of oscillations, showing a period of approximately 150 sec, in the transition region above sunspots; (3) use of density diagnostics to obtain density maps of active regions and indications of density enhancements to 10^{12} cm^{-3} for impulsive events occurring in active regions.
(E.A. Tandberg Hanssen/ES51/205-453-0027)

Solar Magnetograph Research

With the launch of the SMM satellite, MSFC embarked on an intensive ground-based observing program as part of its involvement in the SMM Guest Investigator Program and in support of the SMM Principal Investigators' mission planning operations. In this program, all-day

(weather permitting) observations of active regions under study by SSM experiments have been made with the MSFC vector magnetograph and data have been furnished to SMM experimentors. Auxiliary observations are made with MSFC's H-alpha and white-light telescopes.

In basic research, an extensive analysis of MSFC vector magnetograph data was initiated to study the vector magnetic field of a particular flare-producing solar active region observed by the SMM experiments. Specific investigations have included the study of transverse field orientations near flare locations (Fig. 2) and in magnetic "delta" regions as well as calculations of the active region's total magnetic energy (using a recently "rediscovered" formulation for a generalized force-free field) and comparisons of observed transverse fields with SMM ultraviolet CIV spectroheliograms.

Figure 2. Transverse Field Orientations Near Flare Locations.

In related research, analyses have been initiated to study magneto-optical effects, as seen in the magnetograph data, and a formalism was completed to derive information on solar electric currents from observations with the MSFC magnetograph. In related technology, a solar correlation tracker was integrated into the solar magnetograph system. This unique instrument provides excellent image stability and will serve as a prototype for flight instruments requiring exceptional image stability. (M. A. Haggard/ES52/205-453-0118)

Solar Magnetohydrodynamics (MHD)

The wealth of new solar data made available through the ground-based and satellite observations stimulated a number of theoretical activities in solar magnetohydrodynamics. A new method of treating magneto-fluid dynamic problems has been developed and used to give a better understanding of the nature of solar prominence and solar magnetic fields.

The quiescent prominence poses an interesting nonlinear problem on the static equilibrium of a plasma in the presence of magnetic fields and gravity. Exact mathematical solutions have been found to illustrate (1) the large- and small-scale structure of the prominence and (2) the interaction between force equilibrium and thermal balance. Work is in progress to include the effect of plasma motions, magnetic field diffusion and the stability problem. The results are basic to a physical understanding of prominences. A model has been constructed to illustrate how a quasisteady magnetostatic field may transit abruptly into a dynamical state. This process may play a role in triggering coronal transient eruptions. The theoretical questions about electric currents and magnetic fields in the solar atmosphere are being investigated with regard to the interpretation of data from vector magnetograph measurements. (E. Hildner/ES52/205-453-0123)

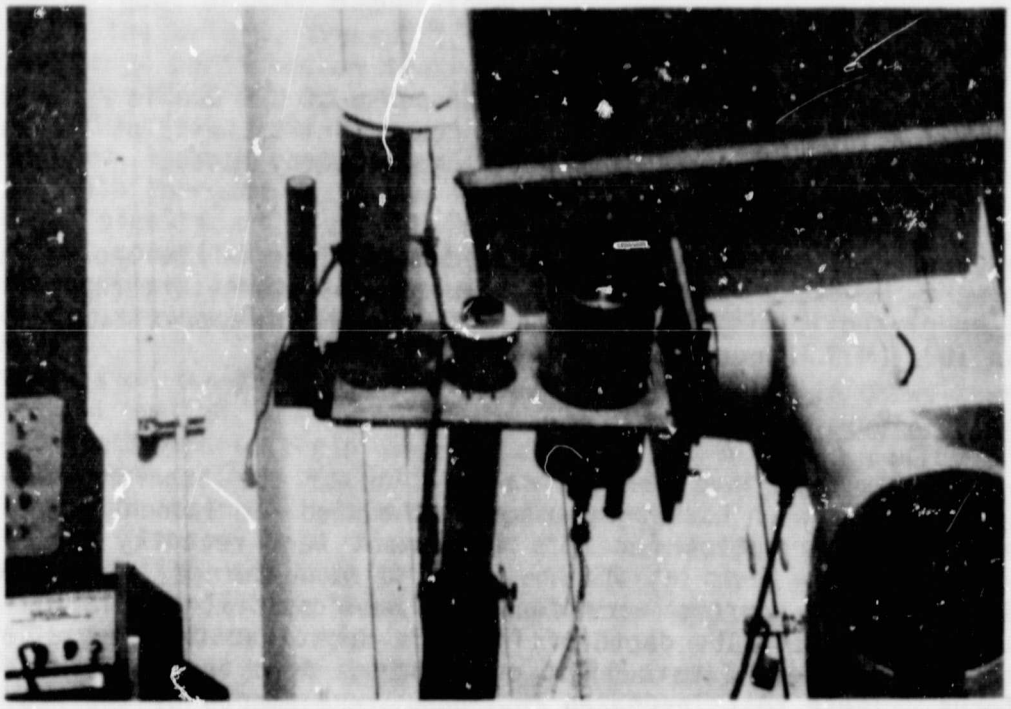

Figure 3. Field Intercomparison of CCR and Absolute Active Cavity Radiometer.

Crystal Cavity Radiometer

MSFC research in measurements of solar irradiance variability to a sensitivity of 2×10^{-5} continued with laboratory stability testing of a crystal cavity radiometer (CCR) and field intercomparisons (Fig. 3) of the CCR with other standard radiometers. The objective of this program is the development of a flight experiment to study dynamics of the solar convection zone and solar interior. Figure 4 shows results of a long-term (20-hour) test of CCR stability which indicate a maximum deviation of 5 parts in 10^4 over the test interval. The major cause of this deviation is attributed to second

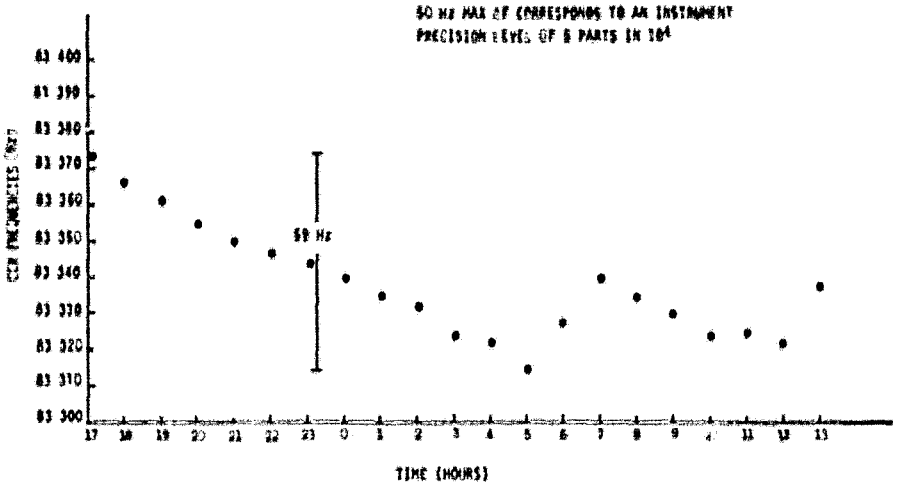

Figure 4. Frequency Response of CCR Due To Applied Electrical Power (Drift Limits of Typical CCR Long-Term Stability Test).

order effects of temperature-induced variations in the applied heating power. However, based on these results, the short-term (approximately 1 hour) sensitivity was measured to a level of approximately 5 parts in 10^5. (M.J. Haggard/ES52/205-453-0118)

Solar X-Ray Imaging

Activities involved the calibration of the Stanford/MSFC X-Ray Spectroheliograph Rocket Experiment scheduled for launch in the spring of 1981. The optics for this instrument were recently subjected to visible light tests at MSFC. These diamond-turned, nested Wolter-Schwarzschild mirrors were found to have spatial resolution better than 5 arc-sec. The depth of field is such that the resolution does not degrade beyond this limit over $\pm$ 1 mm from the position of best focus. These tests revealed the separate elements of the nest to be precisely co-axial and co-focal. This work has enhanced our confidence in the quality of X-ray mirrors fabricated by the low-cost, single-point, diamond-turning technique.

The optics have been returned to Stanford University for final assembly prior to XUV (100 to 300 Å) measurements of their scattering and reflectivity properties. The planned 1981 launch will study the spectrum of the hot white dwarf HZ43 in the approximate wavelength range of 50 to 300 Å with a resolving power of 1 Å. This should resolve edge structure (if present) due to OIV, OV, NIV and NV edges below 200 Å and significantly constrain model atmosphere parameters used to fit the spectrum at longer wavelengths.

After the recovery of the payload, a second (solar) flight is planned to produce high-resolution spectroheliograms over a broad wavelength (4 to 800 Å) and temperature range. The instrumental approach utilized will allow stigmatic XUV and soft X-ray spectroheliograms to be obtained for the first time.

In addition to the rocket experiment, a small (7-inch diameter, 22-inch focal length) X-ray mirror has been designed for the NOAA/NASA GOES satellite X-Ray Telescope Program. These optics are currently being diamond-turned prior to superpolishing. Theoretical analyses performed at MSFC indicates that resolution better than 5 arc-sec should be achieved with these mirrors. This satellite instrument will give routine X-ray images of the Sun which can be used to identify features such as coronal holes. These features are important signatures for locating enhanced solar wind velocity regions that cause geomagnetic activity at the Earth and, hence, are a fundamental part of the solar-terrestrial predictions process. (A.C. DeLoach/ES52/205-453-0116)

MAGNETOSPHERIC PHYSICS

Discoveries in Mangetospheric Plasma Origins

A major goal of MSFC magnetospheric research has been the understanding of the origin, transport, and acceleration processes acting upon low-energy particles in the magnetospheric space environment of the Earth. The MSFC ion detector flown on the International Sun Earth Explorer (ISEE) satellite has returned very exciting information on the densities, energy, angular and compositional properties of positive ions with energies less than 100 eV. In many regions of the magnetosphere, significant fluxes of helium and oxygen ions, in addition to hydrogen, constitute evidence of a generally ionospheric origin of these low-energy plasmas. It has also been learned that ions of different species experience different modes of acceleration in the magnetosphere.

Analysis of ion flux distributions in energy and angle shows that hydrogen and heliun ions appear to experience more acceleration normal to the magnetic field than do oxygen ions in the vicinity of the plasmasphere. This process seems effective in trapping hydrogen and helium ions near the magnetic equatorial plane. Another recent and exciting finding is a flow along the magnetic field lines of hydrogen and helium ions with very low energies (1 to 2 eV). The composition, energy, and directional nature of the ionospheric polar wind outflow have long been sought at high altitudes. There is evidence that this flow is a prime contributor to the plasmaspheric density buildup process. (C.R. Chappell/ES53/205 453-3036)

Low-Energy Plasma Instrument Development

The complex nature of the magnetospheric plasmas has stimulated continuing development of instrumentation techniques suitable for in situ measurement in the Earth's geospace environment. The MSFC Light Ion Mass Spectrometer was the first of a series of upgraded low-energy ion analysis instruments. It was launched aboard the joint DoD/NASA SCATHA satellite in January 1979. This instrument combined mass analysis, energy analysis, and bulk flow analysis by means of multiple sensor heads. Data from the instrument continue to be analyzed, revealing new information on the dynamics of the low-energy plasma in the dusk bulge region of the plasmasphere. The populations of H^+, He^+, and O^+ ions are a strong function of local time and magnetic activity, and very strong plasma flows are measured at the times of onset of magnetospheric substorms. Dramatic changes in the H^+/He^+

ratio are seen as the satellite crosses the plasmasphere-plasmasheet boundary in the night-side magnetosphere.

New information on low-energy magnetospheric plasma distributions led to a further upgrading of the MSFC Swept Angle Retarding Ion Mass Spectrometer (SARIMS). This instrument combines the techniques of electronic angle scanning, a hyperbolic plate energy analyzer, and a permanent magnet mass spectrometer to produce a response to ions which is simultaneously differential in angle, energy, and mass. Following extensive laboratory testing to determine the instrument characteristics, the instrument was successfully flown on two sounding rocket flights in December 1979 and March 1980.

The March 1980 flight was on the University of Michigan sounding rocket MAP-2, launched from Fort Churchill, Canada, near midnight local time into an active aurora. The payload at various times during the flight performed yaw maneuvers to position the instrument to measure ion flows in an east-west direction and at other times to measure flows up and down the magnetic field line. The instrument was programmed to measure the energy distributions and arrival angle distributions of the ions NO^+ and O^+.

The SARIMS operated as planned throughout the entire flight. Significant fluxes of NO^+ and O^+ were detected, with NO^+ densities ranging from 1.0×10^5 ions/cm^3 up to 2.8×10^5 ions/cm^3, with the higher densities having been observed over the discrete auroral arcs. The O^+ densities were less by a factor of 5 to 10. The ion temperatures ranged from 0.15 eV (1740° K) up to 0.33 eV (3830° K) with the higher temperatures again over the auroral arcs, illustrating the heating of the ionosphere by auroral precipitation. The angle scans revealed flows of both NO^+ and O^+ ions of 0.5 km/sec from west to east near the arcs, and the flow velocity decreased markedly inside the arcs. When the instrument was oriented to measure up-down flows, the resultant ion flows measured were consistent with the payload vertical motion. Significantly, the measurements of density, temperature, and flow velocity were made on a vehicle that was charged to approximately 1 V negative in the auroral ionosphere, a potential considerably larger than the ion thermal energy. Such measurements were possible only because of the triply differential (angle, energy, mass) capability of the instrument. The SARIMS will be flown again on the MAP-3 rocket in January 1981; the ions sampled will be O^+ and NO^+, as before, in addition to O_2^+. (C.R. Chappell/ES53/205-453-3036)

Spacecraft Sheath Influences on Plasma Measurement

In any plasma measurement the influence of the measuring device itself on the particles it is trying to analyze is always of concern. The solution of this difficulty for low-energy plasma measurements from spacecraft has been particularly challenging. Unlike the laboratory where the probe potential can be controlled to follow the potential of the plasma being measured, satellites are an electrically floating device and are observed to obtain a wide range of potentials with respect to the ambient plasma. In the case in which the spacecraft becomes attracting to the particles of interest, the satellite can perturb the trajectories of nearby ambient particles and focus them into the detector aperture (Fig. 5). Not only does the total number of particles that enter the aperture of the instrument increase over the number that would otherwise enter, but these extra particles

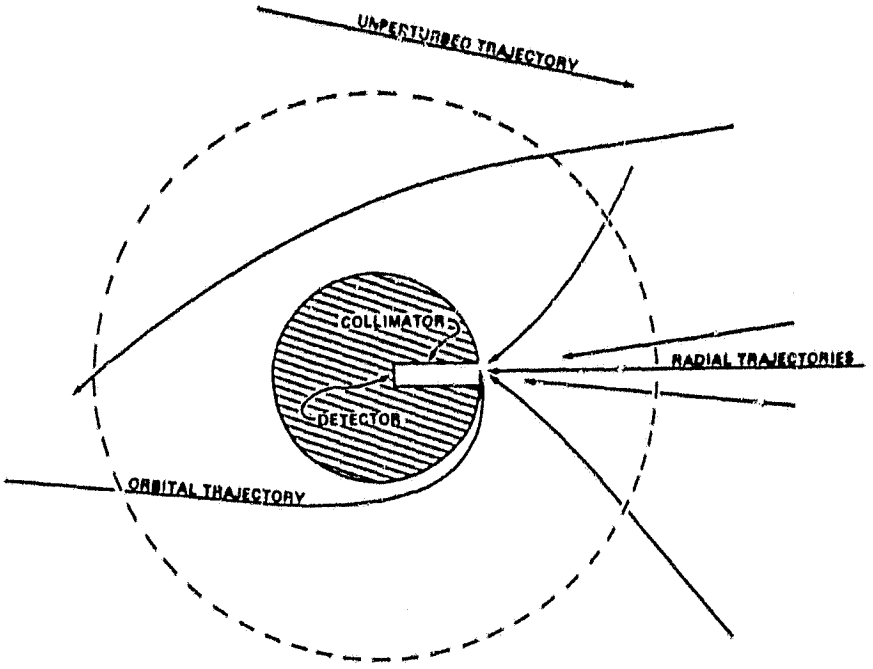

Figure 5. Perturbation of Ambient Particle Trajectories By Satellite Potential.

also have an energy distribution that tends to cover up the ambient low-energy population the instrument is measuring.

Historically, the successful solution of this problem has centered on mathematical approaches that depend on predicting the paths of the ambient particles around the attracting body and evaluating which portion of the measurement is due to the focusing effects. Recently, however, a new generation of low-energy ion instruments has been developed that can provide the majority of the discrimination at the time of the measurement. The approach is conceptually simple. Rather than accepting any particle that enters the instrument's aperture, the incoming ion flow is collimated inside the instrument so that only particles approaching the spacecraft on approximately radial trajectories are actually counted. These particles reach the spacecraft with a minimum of disturbance in their energy properties and are therefore representative of the population in the ambient medium.

Intercomparisons, by MSFC scientists, of data analysis results from the Plasma Composition Experiment on the ISEE & GEOS spacecraft have provided the first test of the concept. In agreement with theory, the ion flux measured by these experiments is substantially free of deleterious focusing effects. This analysis is elemental in the interpretation of the magnetospheric plasma data.(C.R. Chappell/ ES53/205-453-3036)

Plasma Flow-Space Electrodynamic Interactions

Plasma flow studies are directed primarily toward the experimental, laboratory investigation of bodies in a collisionless, mesosonic plasma where the flow velocity is greater than the mean thermal motion of the ions but much less than that of the electrons. Controlled experiments in the laboratory are well suited to the systematic study

of such plasma flow interactions, including the modifications to the plasma flow field and the electrodynamic characteristics of the body. Extrapolation to other regimes of parameter space of interest to space physics is then possible.

In the past year, this approach has been carried out more systematically than previously. The results have been used to gain new insight into Atmospheric Explorer-C spacecraft data on the distribution of electrons around the satellite as a function of angle of attack, electron temperature, orbital velocity, and ion concentration ratios. Laboratory capabilities were significantly expanded by the development of a Dual Ion Accelerator (DIA) that creates a binary plasma in which the concentrations and drift velocities of two ions of different masses can be independently controlled. The DIA has been successfully tested. Preliminary data indicate some interaction effects that are unique to the binary plasma. All previous laboratory investigations have been limited to plasmas having a single ion constituent. Future studies in this area should have a great impact on the validity of the "neutral ion" approximation theory of the spacecraft-space plasma interaction.

Appropriate scaling laws have been applied to determine the enhanced capabilities to be gained by extending laboratory methods and techniques to Shuttle-borne experiments in the Earth's ionosphere. A large class of plasma flow interactions of interest to solar system plasma physics can be qualitatively scaled and properly addressed by such experiments. The interactions of the Jovian moon Io with the planet's magnetosphere is an excellent example. A program of investigations of the plasma-electrodynamic interaction around bodies orbiting within the ionosphere will be a great asset to solar system space plasma physics studies because of its potential for supplementing and aiding in the interpretation of data from planetary missions as well as its potential benefit in planning future missions. Hence, these studies apply across the spectrum of activities from the interpretation of low-energy plasma measurements in the Earth's ionosphere to the simulation of plasma flow processes in distant planetary magnetospheres. (C.R. Chappell/ES53/205-453-3036)

Upper Atmospheric Observations

Upper atmospheric observations carried out at MSFC are oriented toward the understanding of the causes of auroral particle precipitation and the resulting effects on the upper atmosphere. Measurements are currently being conducted with ground-based optical instrumentation which is being upgraded for flight on several future Spacelab missions. These new instruments are called the Atmospheric Emissions Photometric Imager (AEPI) and the High Resolution Doppler Imager (HRDI) and are scheduled for Spacelab 1 and a future Spacelab, respectively.

The ground-based measurements permit the determination of neutral temperature enhancements in and near auroral precipitation events at F-region altitudes. A large-aperture Fabry-Perot interferometer is used to decipher Doppler characteristics of the atmospheric emissions and, hence, the temperatures. These measurements are being extended to include auroral region "winds." A planned meridian chain of the wind measurements will give broad latitudinal coverage of upper atmosphere dynamics.

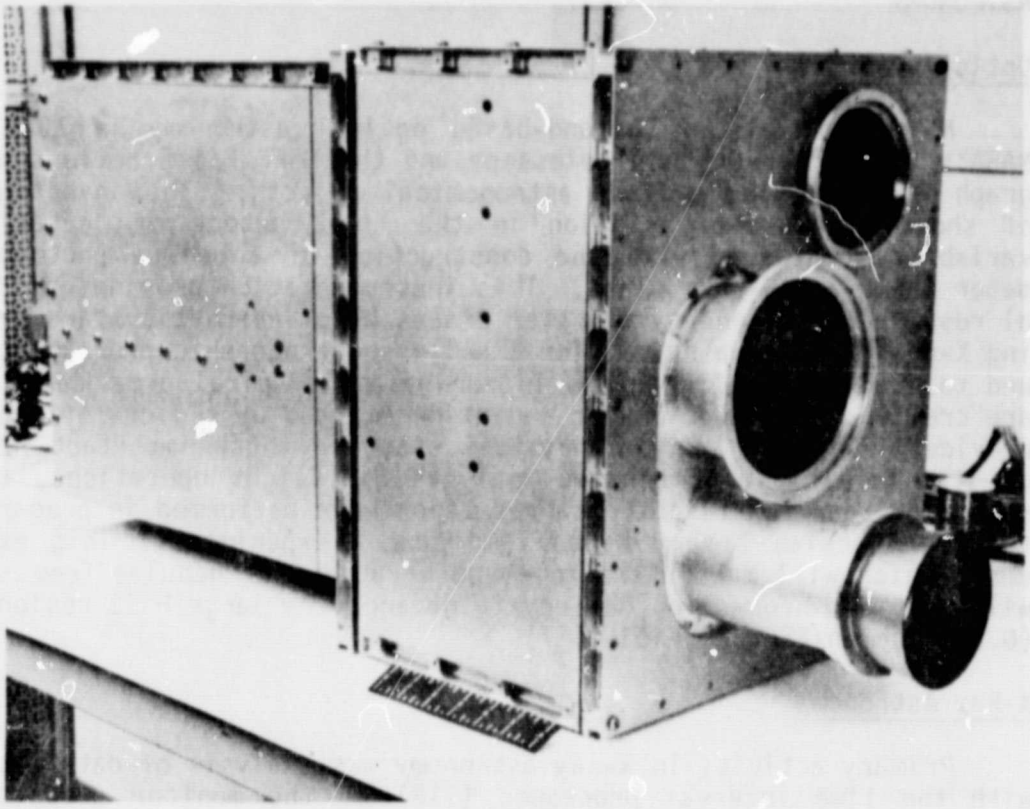

Figure 6 AEPI Detector Box.

The development of the AEPI instrument for Spacelab 1 has been completed, and the instrument is entering the test and calibration phase (Fig. 6). This instrument will permit a large number of active and passive space plasma physics experiments to be performed on the first Spacelab mission, including joint operation with the electron accelerator (SEPAC) being built by MSFC and the University of Tokyo. During the past year, the details of AEPI experiment control, through computer and manned system interfaces, were optimized to provide the best available data on these active experiments and on passive observations of the natural aurora. Two optical channels provide the necessary temporal and spatial resolution of natural and stimulated source emissions. The wavelength range and control flexibility as well as the light-gathering power have been carefully assembled into an instrument offering a new dimension to space-borne optical measurements.

A second Spacelab instrument, the HRDI, is in the early definition phase. This instrument will provide wind and temperature measurements of not only the auroral region atmosphere but also the high-altitude atmospheric dynamics on a global scale. The HRDI and the AEPI techniques contribute to the chain of information that relates solar changes to magnetospheric response and, ultimately, atmospheric effects. This chain represents the fundamental linkage of energy changes throughout our solar-terrestrial environment. (C.R. Chappell/ ES53/205-453-3036)

ASTRONOMY

Optical Astronomy

MSFC's program of ground-based optical astronomy in 1980 used NASA's Mt. Lemmon 60-inch telescope and the MSFC F/4 Echelle spectrograph for observing diffuse astronomical objects. The investigation of short time-scale variation in the light output of "cataclysmic variables" continued with the construction of a unique photopolarimeter using a 1/3-wave plate. This instrumentation provides additional results on the energy transfer processes of energetic stars producing X-rays and gamma rays. The Echelle spectrographic program continued to study the H II regions in our galactic spiral arms where stars are created. Observations of radiation emitted by regions of hydrogen provide information on the physical state in these important regions of star formation. Extensive analysis for flight operations, target selection, and postflight data reduction were performed in preparation for the Spacelab 1 Very Wide Field Camera experiment. This experiment, which will make ultraviolet observations of nebulae from space, will provide information on very faint and very large H II regions. (G.H. Fishman/ES62/205-453-0117)

X-Ray Astronomy

Primary activity in X-ray astronomy was analysis of data obtained with the time interval processor (TIP) of the monitor proportional counter (MPC) aboard the HEAO-2 satellite. The observation of the intense burst from the transient event of March 5, 1979 (Fig. 7) was of particular interest. This extremely unusual event appeared to originate near a supernova remnant in the Large Magellanic Cloud. Another result of this work led to a new measurement of the period of the pulsating binary X-ray source SMCX-1, the characterization of its period fluctuations, and the theoretical speculation that it may be a "slow" rotator in its low state.

Definition of the Advanced X-Ray Astrophysics Facility (AXAF) continued. System and subsystem requirements were further refined, and experiments were defined to greater detail with the emphasis centering on X-ray technology and the optics required for the experiment. The report of the AXAF Science Working Group was completed and published. The AXAF, now planned for a 1984 new start, will be similar to the Space Telescope operationally in that it will be a long lifetime major astronomical facility. The AXAF optics will have a 1.2 m aperture as contrasted with HEAO-2's 0.6 m aperture, and the instrument's energy range and spatial resolution sensitivities will be significantly improved. For example, X-ray imaging will be possible to subarcsecond resolution. (M.C. Weisskopf/ES62/205-453-5133)

Cosmic Ray Research

Cosmic ray research at MSFC currently concentrates on the measurement of the flux and relative abundances of lithium through iron, utilizing a balloon-borne instrument which incorporates massive stacks of photographic emulsions and electronic detectors to record the passage and interactions of high-atomic-number cosmic rays. During 1980 this research was further strengthened by the MSFC group becoming part of a large collaborative international team with other institutions from West Germany and Japan, as well as other U. S. investigators.

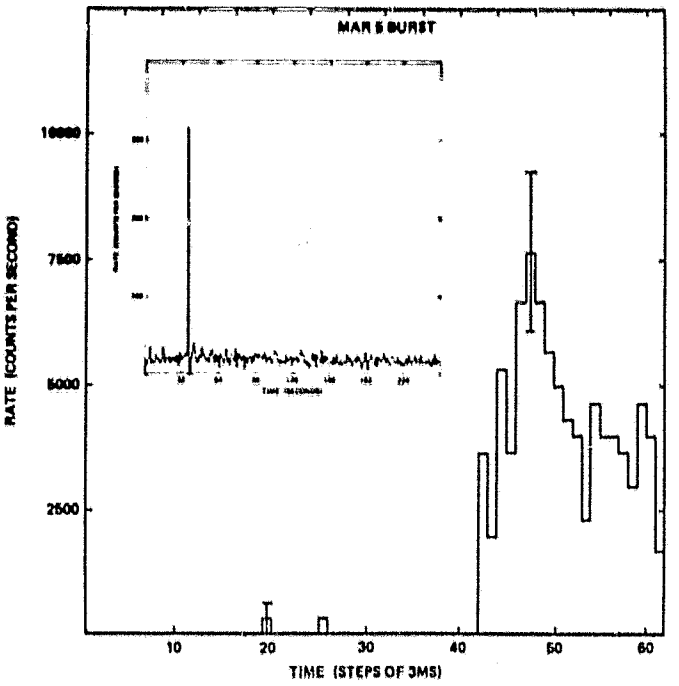

Figure 7. MPC Observations of the Transient Burst of March 5, 1979.

In addition to basic research on the energy and composition of the primary cosmic radiation, the research will contribute significantly to the field of high-energy particle physics. Through the study of the interactions of the primary particles with the nuclei of the photographic emulsion, processes may be observed at energies far greater than that possible using Earth-based nuclear accelerators. The experimental instrumentation also investigates the feasibility of using acoustical detectors for cosmic ray research. At very high energies, the passage of a single nucleus through a dense material gives rise to a thermal-induced shock wave in the material. High-frequency microphones can record this passage and may be a superior method for determining the energy and charge of cosmic rays in large-area instruments. (T.A.Parnell/ES62/205-453-5133)

Gamma-Ray Astronomy

Work in gamma-ray astronomy emphasized the study of gamma-ray burst sources through the development of high-altitude, balloon-borne experiments (Fig. 8) and through the analysis of satellite data. Significant improvements were made in large area scintillation crystal detectors used in studying the rate, spectrum, and location of the enigmatic cosmic gamma-ray bursts, the origin of which is still speculative. The search for an optical counterpart from the bursts has thus far been futile. The detector system has been flown on several balloon flights and is a forerunner of an experiment planned for the Gamma-Ray Observatory, to be launched in 1985. In addition to the analysis of balloon-flight data, a Guest Investigation to study gamma-ray bursts from HEAO-1 data is continuing.

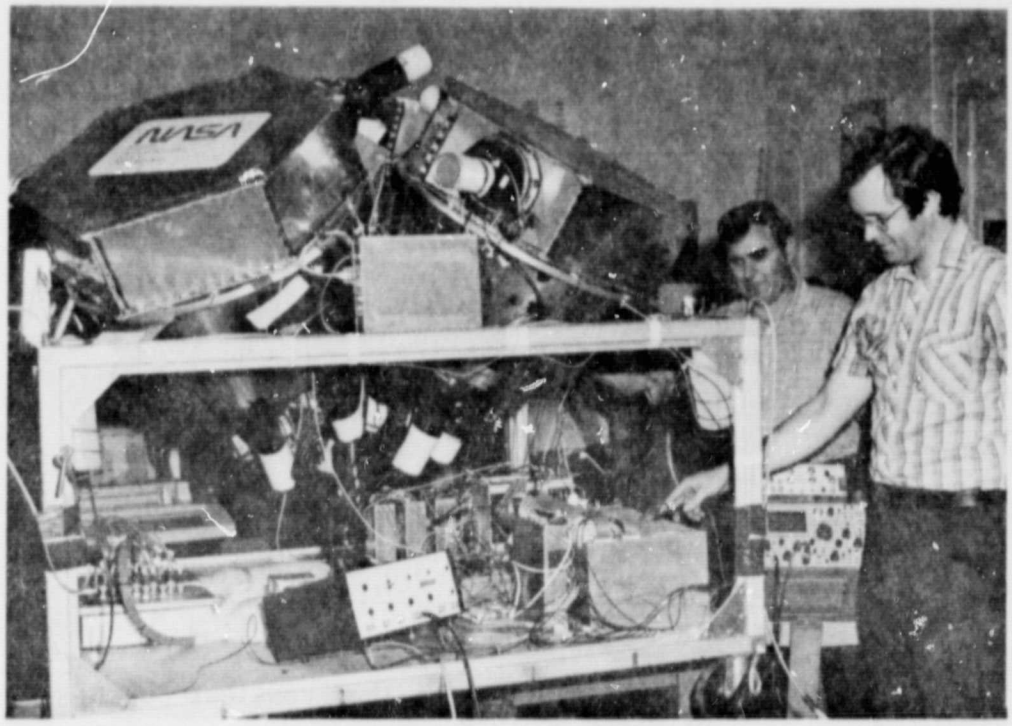

Figure 8. Balloon-Borne Detector Instruments Undergoing Checkout for Flight.

COMETARY AND METEOROID RESEARCH

Meteor Spectra Research

MSFC continued analyzing meteor spectra recorded with low-light-level vidicon systems to determine chemical abundances of particles originating from selected meteor showers. Meteors are believed to be residual matter ejected from comets and left behind in the cometary orbit. The study of the spectra of meteors belonging to major meteor showers is unique because it is the only observational field in astrophysics that permits a chemical and physical study of a specific small particle known to be a fragment of an identified comet. In the video spectral analysis, particular attention was given to the calibration of the video system used in obtaining the data, and a preliminary photometric curve was determined. From this, the abundances of Ca, Mg, Fe, and Na are being calculated for meteors associated with selected showers, and general luminous measurements for many elements are being tabulated. The computed abundances will be compared with those obtained from other small bodies in the solar system. (K.S. Clifton/ ES64/205-453-2305)

Cometary Research

The MSFC spectrographic study of comets is part of an effort to classify comets by their spectral characteristics. It has provided information on the mechanism of emission from comets. Theoretical investigations of the optical emissions of carbon molecules in

cometary atmospheres continued in 1980. Detailed interpretation of the resonance fluorescence mechanism and observational comparison of the Phillips and Swan band ratios were performed. This information is essential to the quantitative understanding of the physical conditions in cometary coma and the nature of the cometary surface. (G.A. Gary/ES62/205-453-0110)

CRYOGENICS AND SUPERCONDUCTING INSTRUMENTATION

For many years, MSFC has been active in research and development programs directed toward improved superconducting instrumentation for space research and toward the application of superfluid helium for efficient, long-term cooling in space. Research was directed toward meeting increasingly demanding performance and sensitivity requirements of the experimental gravitation physics program and of related disciplines, such as infrared astronomy. The effort involves not only the sensitive superconducting circuit elements themselves, but also their integration into more complex apparatus. Refrigeration studies have concentrated on the behavior of superfluid Helium-4, special devices for its control, long-term storage and use of superfluid liquid helium in space, and an advanced refrigeration using Helium-3. They also include research into insulation techniques, flow-control components, and multipurpose dewar systems.

Superconducting Instrumentation

Research and development in superconducting instrumentation is being conducted with emphasis on thin film devices. The optimization of Josephson junctions fabricated in thin films for application to Superconducting Quantum Interference Device (SQUID) magnetometers and sensors and mixers of electromagnetic radiation is being pursued.

Exceptionally rugged, planar, thin film, rf SQUID's with sensitivities of 2×10^{-19} Weber/ Hz have been fabricated in sputtered niobium films. Earlier problems with very narrow temperature operating ranges, fabrication difficulties, and obtaining devices with predictable characteristics have been largely overcome, and it appears feasible to adapt recently fabricated devices to mass production techniques. As presently developed, these planar devices are comparable in sensitivity to bulkier point contact devices and have the advantages of being more rugged and utilizing microcircuit fabrication techniques. Because they contain a weak link in pure niobium, they are insensitive to galvanic corrosion, and rapid temperature cyclings do not modify their characteristics.

The methods of fabricating Josephson junctions for the rf magnetometers are now being applied to dc SQUID circuits with the anticipation of obtaining even higher sensitivities; the improved reproducibility in characteristics can hopefully be applied advantageously to improving coherent arrays and their response to electromagnetic radiation.

Prototype superconducting readout systems utilizing niobium films have been fabricated for the GP-B Experiment; applications to the Gravity Gradient Experiment have been discussed, and applications to other flight experiments are envisioned. (P.N. Peters/ES63/205-453-5134)

Superfluid Helium

Studies in cryogenics for the past several years have concentrated on the long-term storage and use of liquid helium in space. A helium dewar system was designed using modified commercial apparatus and costing about one-fifth that of conventional high-performance space dewars. It will be efficient and versatile enough to supply helium cooling to a variety of Spacelab experiments. Testing and integration of the cryogenic components are now in progress.

Studies of porous plugs as thermally controlled superfluid valves without moving parts have led to an understanding of superfluid control problems and have demonstrated that certain inexpensive, commercially available materials operate well as such valves. Work is continuing to optimize cooling control when thermal conditions vary rapidly over wide ranges. Methods are being studied for the on-orbit conversion of normal helium to superfluid helium to simplify flight hardware and prelaunch ground operations.

A gaseous helium flowmeter was designed with reduced flow impedance. It minimizes thermal control perturbations on a dewar system. Studies have continued on other cryogenic instrumentation, control methods, and safety devices for space apparatus. Research has begun on a continuous flow refrigerator concept that uses Helium-3 as the working fluid to cool small apparatus to approximately 0.2° K. Special cryogenic components have been designed and are being tested for incorporation into flight experiments. (E.W. Urban/ES63/205-453-5132)

SUPPORTING SPACE FACILITIES DEVELOPMENT

Science and Applications Platform

During the past year, experiment definition/accommodation and conceptual design studies for this platform were completed. The initial phase of this facility (Fig. 9) could be available in the mid-1980's. As envisioned, it would extend an unmanned Spacelab's operational stay for durations of six months or longer. A User Review Group, drawn fron the scientific community, helped establish requirements and directions for use of this concept in low Earth orbit. As the platform is presently envisioned, as many as three Spacelab-type pallets would be accommodated. Periodic visits by the Space Shuttle every six months would allow exchange of these pallets with other pallets containing different complements of instruments. (W.C. Snoddy/PS01/205-453-3430)

Gyroscope Relativity Experiment

This experiment, also known as Gravity Probe B, is being developed in cooperation with Stanford University (Fig. 10). Its purpose is to measure the relativistic precession of ultra-stable gyroscopes in Earth orbit, thereby providing a test of Einstein's General Theory of Gravity. The optical performance of the star-tracking telescope has been demonstrated. This uniquely-designed telescope is made of quartz for extreme dimensional stability required for the experiment.

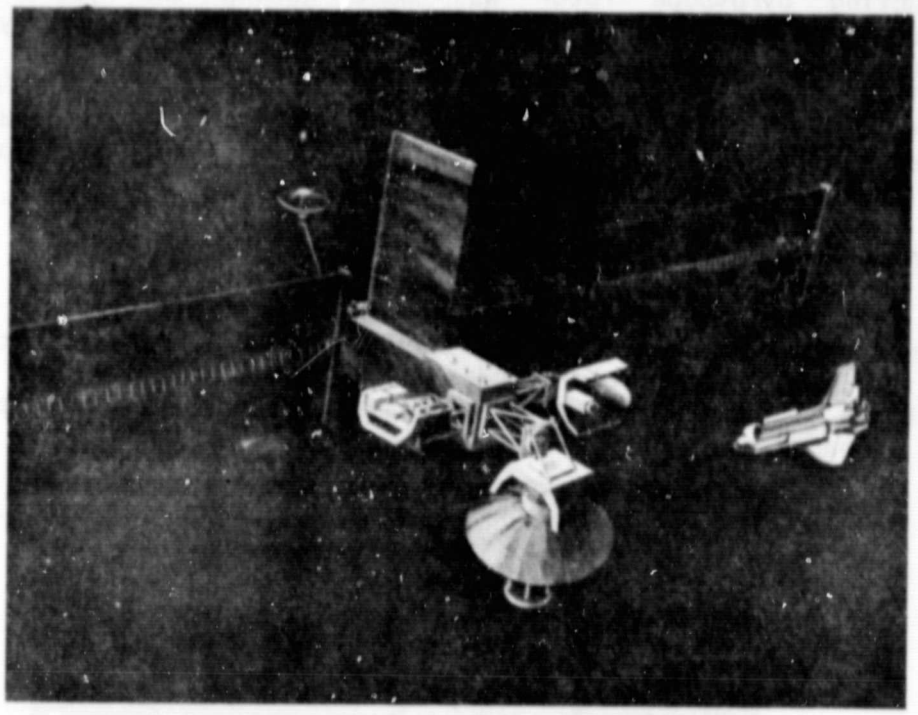

Figure 9. Science and Applications Platform.

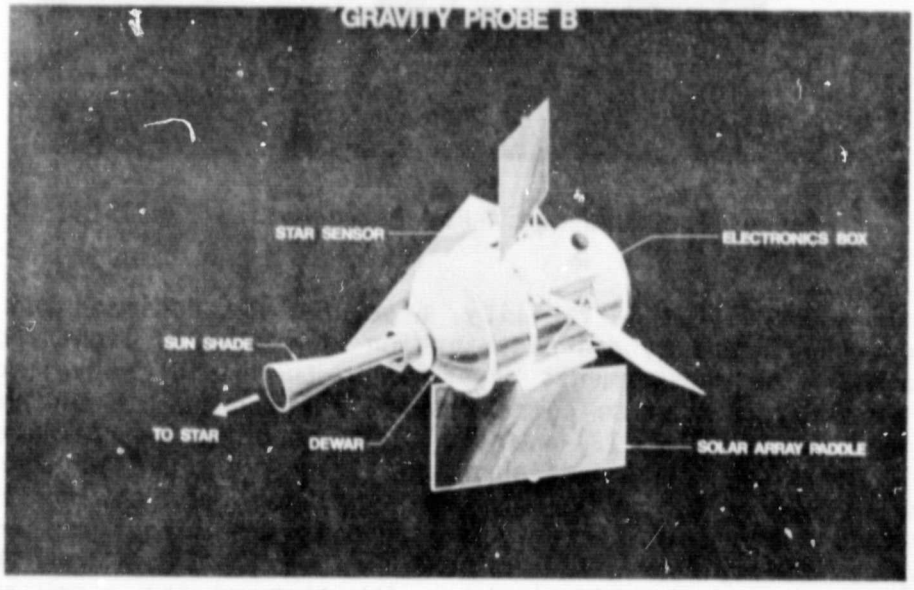

Figure 10. Gravity Probe B Experiment Package.

A very accurate readout of the London moment generated by the superconducting gyroscope rotor was made during the year. These measurements confirmed the feasibility of the novel readout system for measuring the spin axis precession. It was shown that torques resulting from the electrostatic support system in the experiment can be reduced sufficiently in a low-g environment to permit measurement of relativistic drifts predicted by the General Theory of Relativity. (A.K. Neighbors/PF16/205-453-1220)

Advanced X-Ray Astrophysics Facility

This year the phase A concept for this facility (Fig. 11) was refined and updated. It is now documented as a "reference concept." The facility is presently being planned for a new start in FY 1984. Drafts of a request for proposals and announcements of opportunity were prepared.

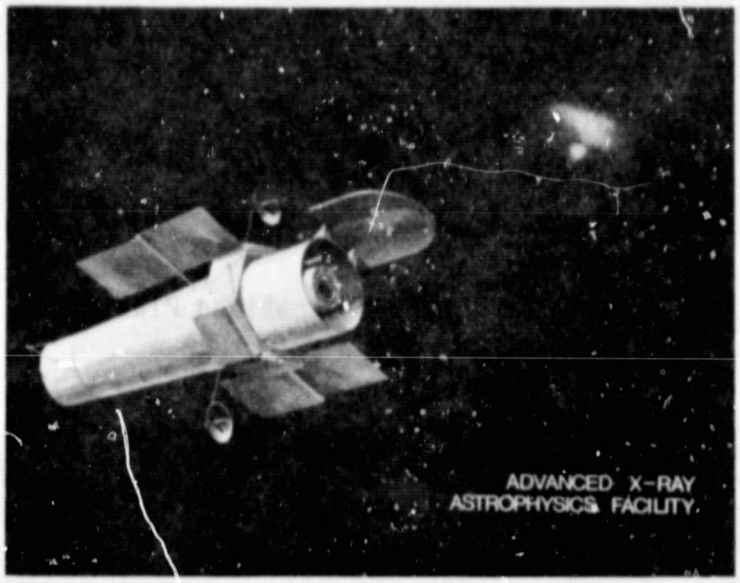

Figure 11. Advanced X-Ray Astrophysics Facility.

In support of this facility, a scanner was designed and built to measure the intensity and distribution of scattered light from mirror surfaces. The measurements are made in the visible wavelength band, and the data is used to compute surface roughness of the mirrors. A special fixture (Fig. 12) was built for mounting two pairs of mirror sample in a periscope configuration. The principle of operation is shown in Figure 13. This fixture is placed near the center of the 1000-foot x-ray test facility and permits the direct measurement of x-ray scattering from sample mirror surfaces. This allows the direct comparison of visible light data with that of the x-ray scattering data. These devices will be instrumental in selecting material and techniques for producing the x-ray mirror for the Advanced X-Ray Astrophysics Facility. (C.C. Dailey/PS01/205-453-2788)

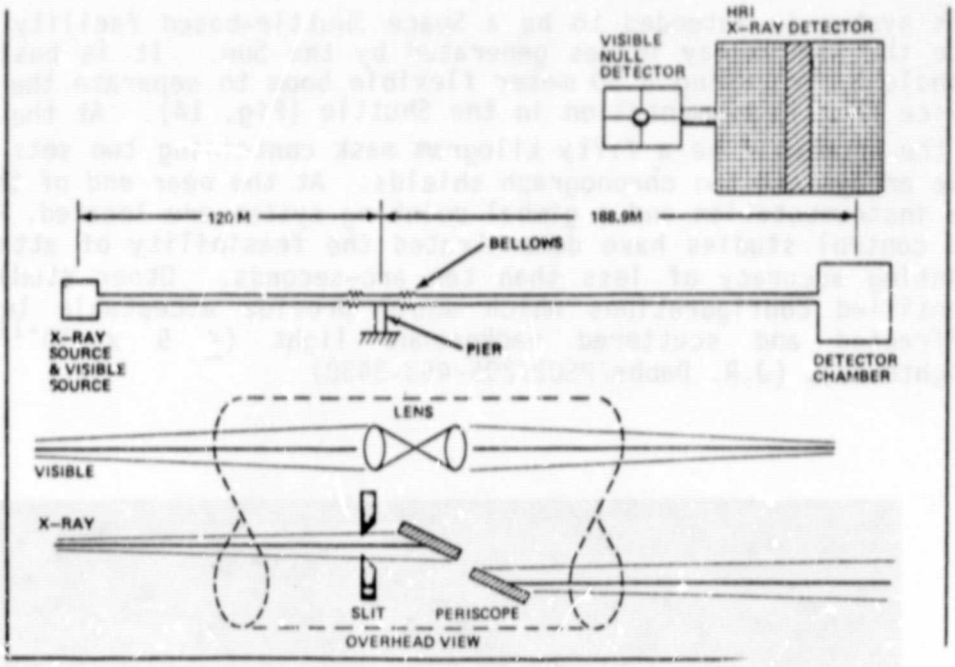

Figure 12. Fixture for Measuring Light Scatter of X-Ray Mirrors.

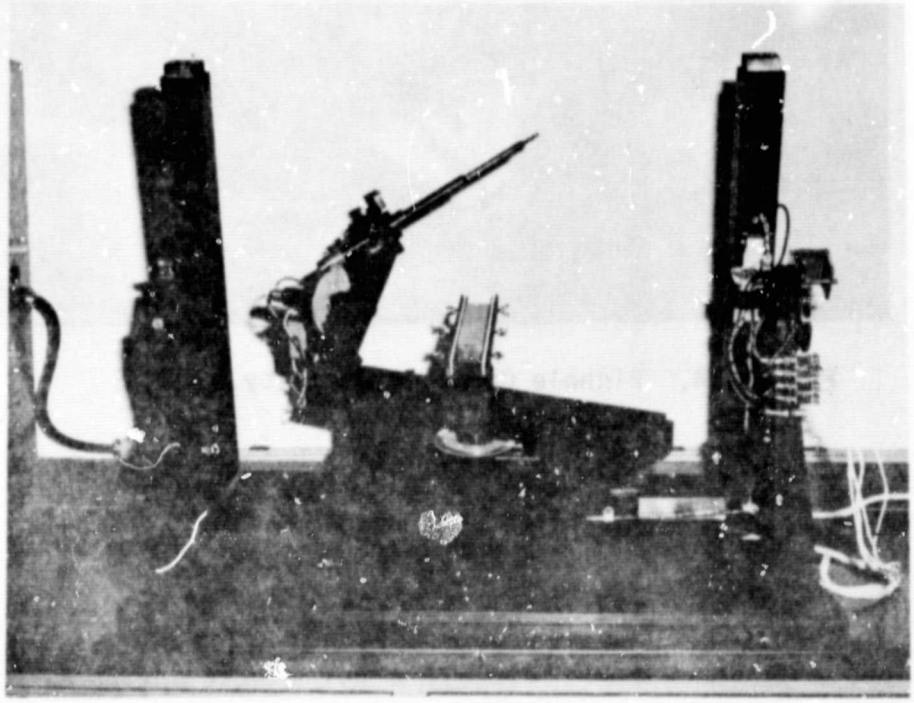

Figure 13. Layout for Scatter Measurements.

Pinhole Occulter Facility

This system is intended to be a Space Shuttle-based facility to produce the hard x-ray images generated by the Sun. It is basically a pinhole camera using a 50 meter flexible boom to separate the pinhole device from instrumentation in the Shuttle (Fig. 14). At the far end of the boom will be a fifty kilogram mask containing two sets of pinhole arrays and two chronograph shields. At the near end of the boom, the instrumentation and a gimbal pointing system are located. Pointing and control studies have demonstrated the feasibility of attaining a pointing accuracy of less than ten arc-seconds. Other studies have identified configurations which would provide acceptable levels of diffracted and scattered background light ($\leq 5 \times 10^{-11}$ solar brightness). (J.R. Dabbs/PS02/205-453-3430)

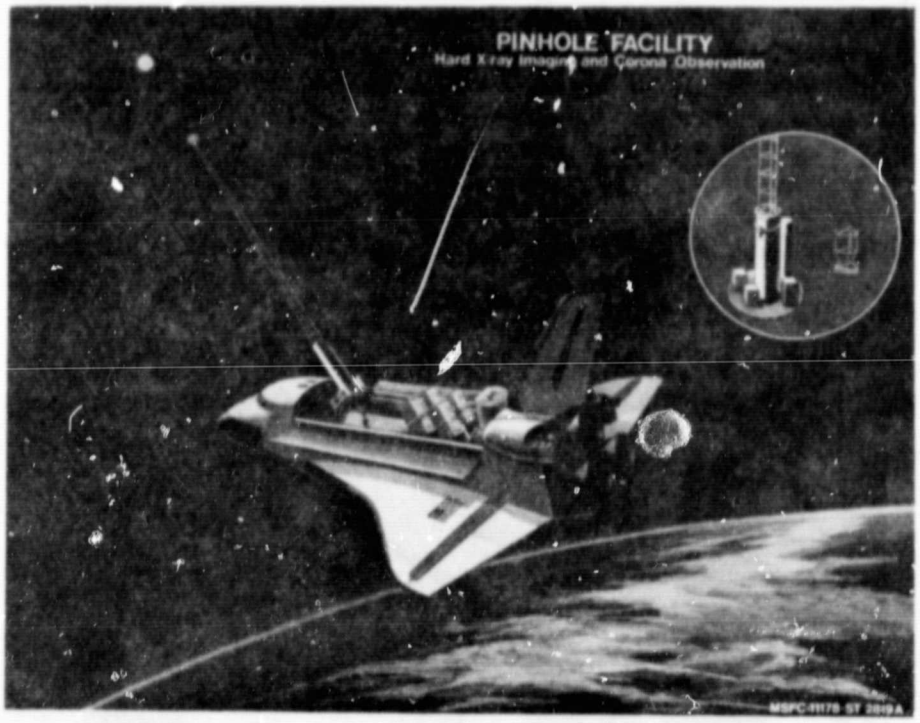

Figure 14. Pinhole Occulter Facility.

SPACE TRANSPORTATION SYSTEMS

Space Transportation Systems are not limited to launch systems for low-Earth orbit missions only. Additional systems are required for orbital transfer to geosynchronous orbit, for on-orbit supplementary power, for specialized experimentation, for satellite placement, service and retrieval, for specialized thermal protection, and for large platforms. MSFC is engaged in a number of projects which will lead to enhancement of the Shuttle orbital capabilities in future space projects.

ADVANCED SYSTEMS

Solar Electric Propulsion System (SEPS)

The SEPS (Fig. 15) is an advanced system for transferring payloads from low-Earth orbit into planetary and higher energy trajectories. In addition, it will provide power and other services to its associated experiment payloads. Key technologies are Large Lightweight/High Power Solar Arrays, High Efficiency 30-cm Ion Thrusters, and High Voltage/High Power Power Processors (page 31). In support of the Phase B studies, MSFC has investigated the following areas: (1) the use of current state-of-the-art transistors and testing of development capacitors in the high power circuits of the 30-cm Ion Thruster Power Processor; (2) investigation of Solar Cell performance for deep space missions, (3) low thrust mission/trajectory analysis; and, (4) dynamic control analyses of large flexible bodies. MSFC has also been involved in the OAST/LeRC 30-cm Ion Thruster Technology data base. This activity has entailed design reviews, discipline discussions, hands-on hardware training session, and failure analyses.

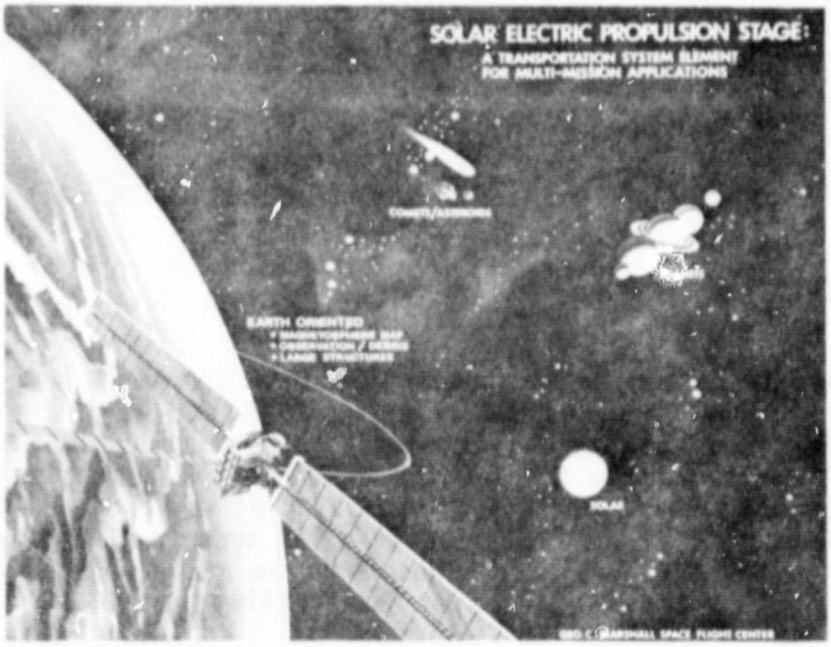

Figure 15. Solar Electric Propulsion System

The planned first use for SEPS is a Comet Rendezvous mission in the 1986-1988 timeframe. A Solar Probe mission to be launched in 1988 is also a candidate. MSFC awarded parallel SEPS Phase B definition studies in December 1979, in anticipation of a 1981 or 1982 new start.(John Harlow/PF13/205 453-3322)

25 kW Power System

This orbit-based system will provide power, thermal control, stabilization and communications to free-flying payloads left on-orbit by the Space Shuttle for long durations. In addition, it can also provide these resources to augment the Orbiter's capabilities for long-duration Spacelab sortie missions requiring manned involvement. The current concept is shown in Figure 16. The Power System represents the first space platform for experiment pallets which will be exchanged, serviced and maintained by the Space Shuttle. Its evolution wil lead to larger unmanned platforms with greater capabilities and, eventually, manned stations. (R.E. Mitchell/PF13/205-453-3405)

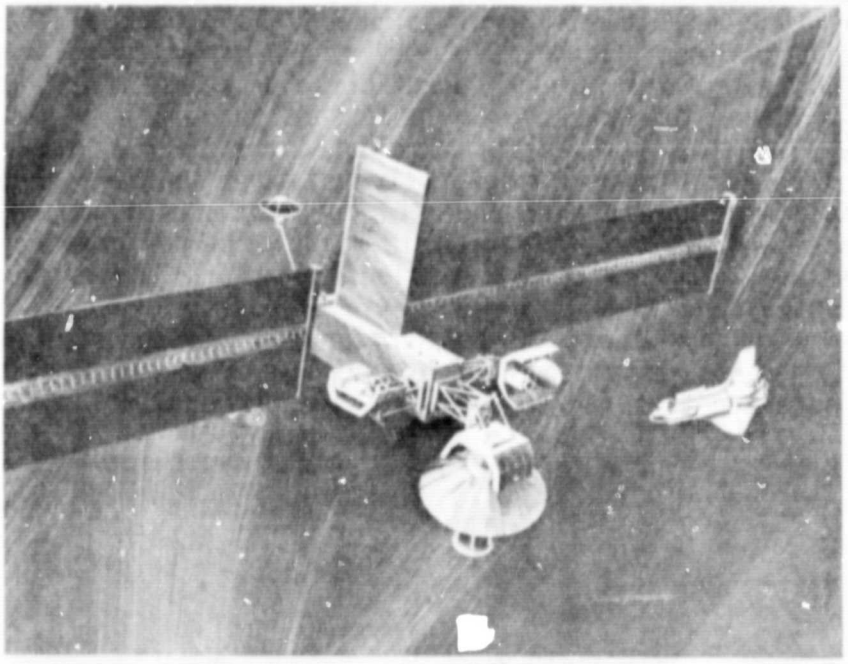

Figure 16. 25 kW Power System.

Alternate System Design Concept Studies (Phase B) were initiated with TRW and MDAC in June 1980. The major objective of these studies is to determine the payload accommodations required by the various potential users, and to develop the best design to meet these needs. Also supporting these Phase B system studies are definition studies with LMSC and TRW of the Power System solar array emphasizing a common design with the SEPS project. These studies are scheduled to support an FY-83 new start and a projected availability in 1986.

In parallel with the system definition, MSFC is conducting several advanced development activities in critical areas. Of particular significance are solar array technology (also supporting the SEPS project), development of a Programmable Power Processor (P^3) for use as a battery charger and regulator, and the assembly of a power system breadboard as a functional verification test of the total integrated power system. (C.C. Gregg/PM01/205-453-5310)

Figure 17. Teleoperator Maneuvering System.

Teleoperator Maneuvering System (TMS)/Remote Satellite Servicer

The Teleoperator Maneuvering System (TMS) Mission Requirements and Systems Definition Study was initiated during the year with contract completion scheduled for the second quarter, 1981. The initial study concept (Fig. 17) is 13 feet in diameter and designed for minimum length in the Shuttle payload bay (about 4 feet). Main propulsion is provided by 8 thrusters at 115 lb. thrust each using monopropellant hydrazine. The concept shown carries 5000 lb. of propellant with growth options to 6,000 - 12,000 lb. The vehicle dry weight is about 2,100 lb and includes a retractable docking probe and solar array for extended stay time in orbit. Performance of the vehicle shown provides 3700 ft/sec of velocity with a 5,000 lb payload. Man-in-the-loop remote control is provided from the Orbiter aft flight deck or from the ground via TDRSS.

The concept is designed to enhance the STS services/capabilities by providing propulsive performance, more flexibility for multiple payload manifesting, and satellite services/operations support in

orbits beyond the Shuttle's capability or where dynamic disturbance/payload contamination requirements constrain "close-in" Shuttle operations. Current planning provides for satellite supporting development activities during the year, including purchase of an RMS end-effector and grapple fixture from SPAR. These will be evaluated for use as a docking mechanism using the air-bearing floor facility and also the six-degree-of-freedom motion system simulation facility at MSFC. The air-bearing floor five-degree-of-freedom facility was used to continue evaluation of the MMS berthing interface for docking and this MMS simulation is being adapted to the six-degree-of-freedom system for futher evaluation.

An activity was initiated for preliminary evaluation of the short range CW radar (developed for coal mining operations) for use as a terminal rendezvous/docking radar sensor for TMS, where precise range rate measurements between TMS and a target spacecraft are required. (D.C. Cramblit/PF14/205-453-1220)

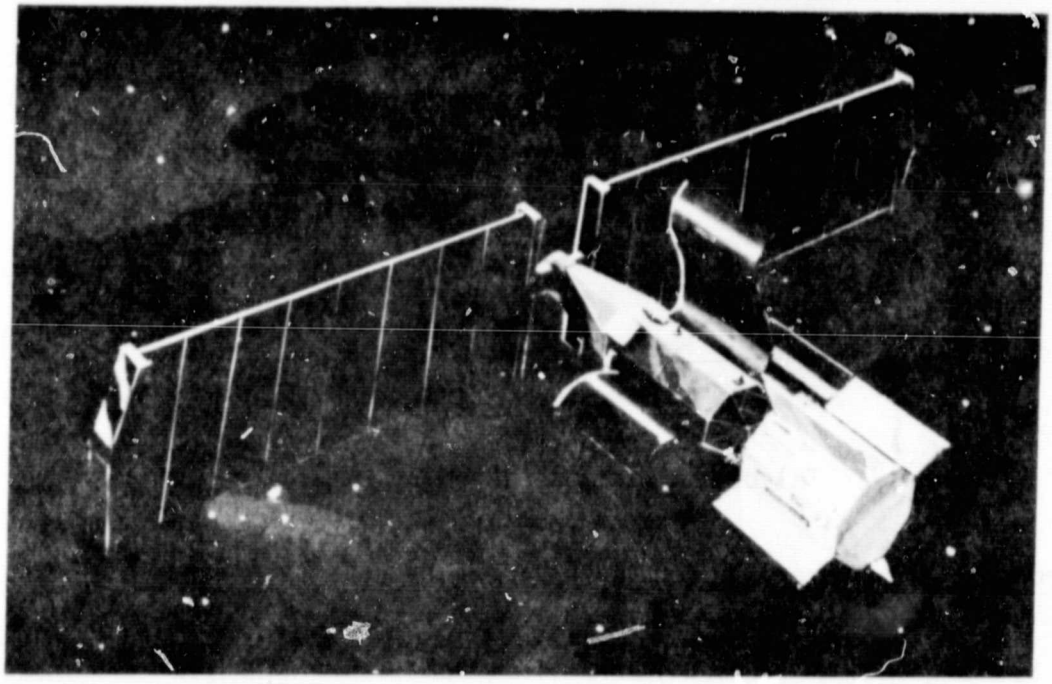

Figure 18. Materials Experiment Carrier.

Materials Experiment Carrier (MEC)

Payloads for the Materials Processing in Space (MPS) Program are characterized by high power and long orbital duration requirements. The MEC has been proposed as an optimized carrier to fly in conjunction with the Power System as a means of satisfying these requirements (Figure 18). The MEC provides the structure and associated subsystems needed to support the MPS payloads. Some eighteen concepts for MEC were defined and analyzed resulting in two competitive that are now being traded against maturing MPS payload requirements. An IRD (Interface Requirements Document) which specifies MEC interfaces with the Power System and nine MPS payloads has been developed.

Current studies indicate that major technology developments are required for the development of high temperature thermal systems to support the MEC payloads. Also required is an avionics system incorporating automated command data management hierarchy that will minimize data transmission to the ground. A supporting study for high temperature thermal control system is underway. The MEC is currently projected for a new start in 1983. (G.B. Wallace/LA21/205 453-2511)

Tethered Satellite System

The Tethered Satellite System (Fig. 19) will provide an important new facility for conducting scientific experiments and operations in regions remote from the Space Shuttle Orbiter. The concept envisions use of a long tether with closed-loop control, capable of supporting a satellite or payload suspended from the Shuttle Orbiter cargo bay, toward or away from the Earth, at distances up to 100 kilometers from the Orbiter. The Tethered Satellite System is expected to open the way to several entirely new areas of long term scientific experimentation, including space plasma physics, electromagnetic wave generation, and observations of crustal geomagnetic pheonomena and atmospheric processes.

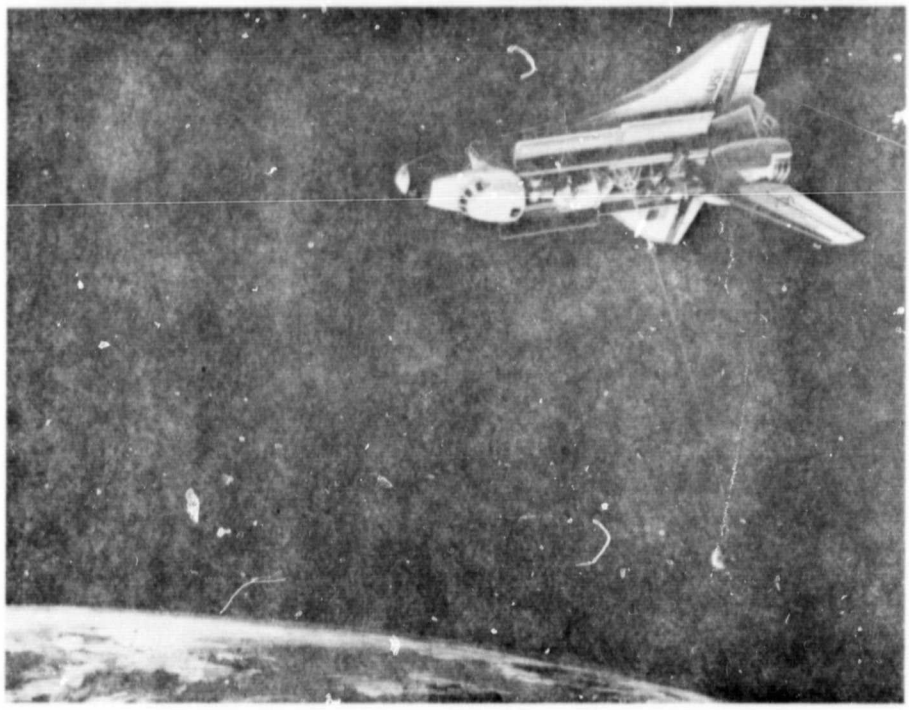

Figure 19. Tethered Satellite System.

Following concept initiation by the Smithsonian Astrophysical Observatory in 1974, early conceptual definition studies were accomplished by the Marshall Space Flight Center (MSFC), including formulation of the basic control law for closed loop control of the system. System definition studies were carried out from 1977 to 1980. User requirements studies were also carried out by a Facility Requirements

Definition Team comprised of scientists from various government and university areas of interest. The Office of Space Transportation Systems, the Office of Space Science, and the Office of Space and Terrestrial Applications have supported the tether system definition studies. Plans are now being formulated for development of the system to be used for the initial demonstration/verification flights and, subsequently, as a science facility for flights in the mid-80's and beyond.(J.H. Laue/PS01/205-453-0163)

Experimental Geostationary Platform

During 1980, extensive studies to determine the feasibility of concepts for Operational Geostationary Platforms for the 1990's were completed. These platforms include a variety of U.S. Domestic and International missions providing for projected traffic in such service areas as long distance telephone, data/facsimile transmission and video links. Advanced meteorological missions as well as DOD missions could also be accommodated on these platforms. NASA interest in these platforms is to develop and demonstrate during the 1980's the technologies and systems capabilities necessary for operational platforms

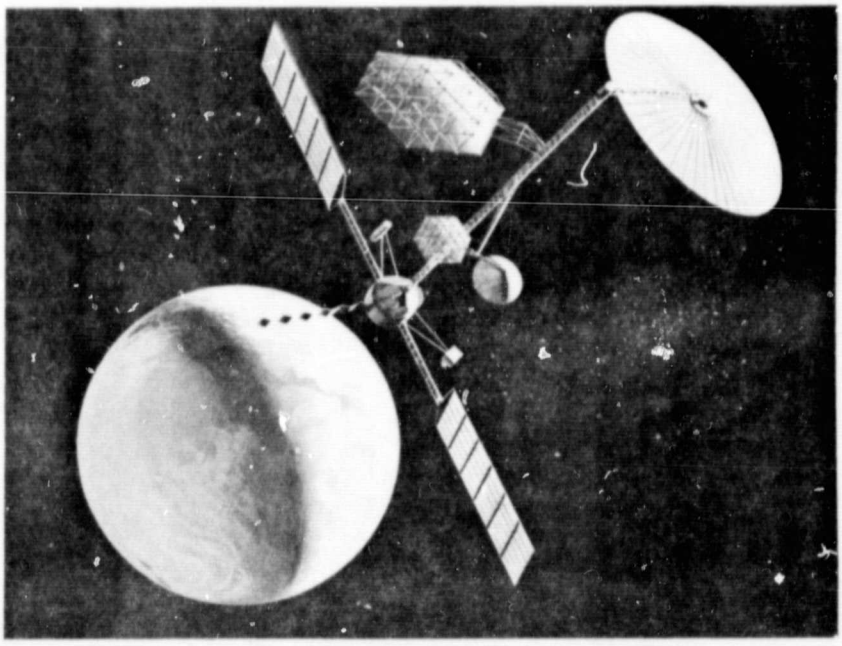

Figure 20. Experimental Geostationary Platform.

of the 1990's. The requirements for, and concepts of, a NASA Experimental Platform which would demonstrate these technologies and systems capabilities were studied in 1980 (Figure 20). Studies of the Experimental Geostationary Platform have been supported by both the OSTS and OSTA.(W.T. Carey/PS06/205-453- 3424)

Orbital Transfer Vehicles (OTV)

Orbital Transfer Vehicles (Fig. 21) using high performance chemical propulsion systems are needed for transporting payloads of up to 7,000 kilograms between low-Earth orbit and geosynchronous orbit. Interplanetary missions are also anticipated which desire similar capability. Studies conducted during 1979/80 defined specific mission applications and requirements and defined candidate evolutionary vehicle concepts to meet these requirements. These studies have identified and initiated definition of deployable aeroassisted vehicle concepts which offer significant performance improvement for reusable transportation to geosynchronous orbit.

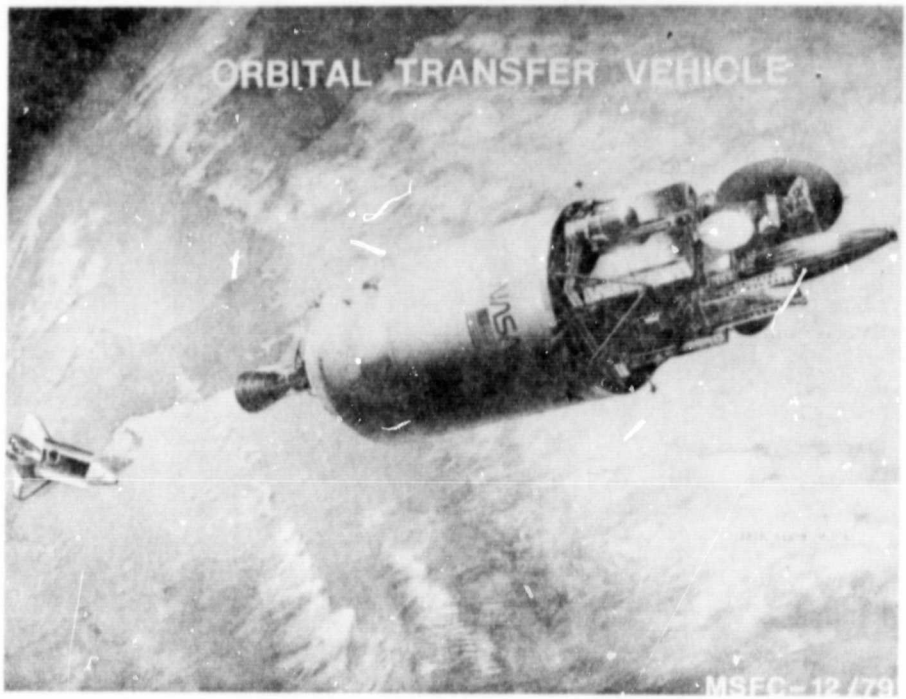

Figure 21. Orbital Transfer Vehicle.

Ground Launched Transportation Systems

MSFC continued its broad based program of Shuttle derived vehicles and improvment studies (Figure 22). Specific studies were performed on the use of liquid propellant boosters as a possible replacement for the Solid Rocket Boosters to increase the payload and to decrease operational costs. Methane, propane, RP-1 were investigated as fuels for the booster. Concepts were investigated for Shuttle derivatives which is a vehicle with the Orbiter replaced with a cargo carrier and a recoverable, reusable combination avionics and propulsion module to increase payload weight and/or volume capability. These concepts provide payload capabilities of 45,000 to 113,000 kilograms and are being used to identify technology requirements and to refine design definition and performance requirements.

Studies to enhance the Shuttle payload capability through product improvement and auxiliary systems are continuing. Increased SSME performance of 115% - 130% of rated power level, stretched External Tank, Solid Rocket Motor composite cases, and supplementary propulsion pods are being investigated for performance and cost benefits.
(J.W. Cole/PD34/205-453-3938)

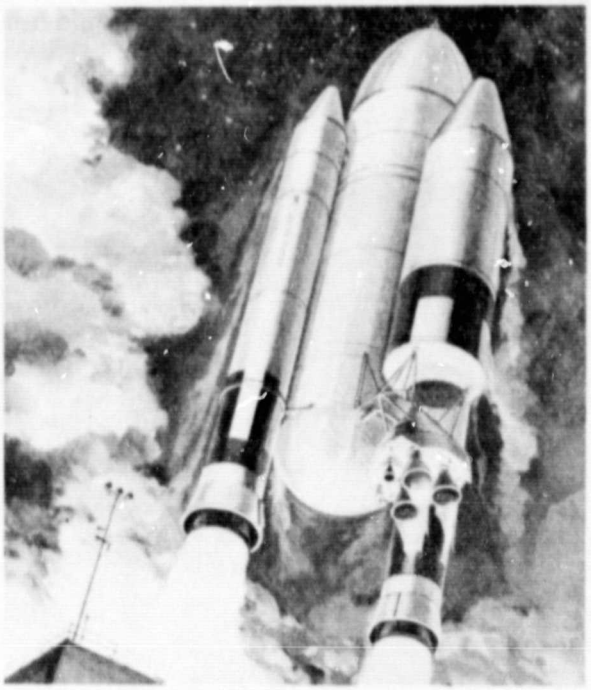

Figure 22. Shuttle Derived Cargo Carrier.

Large Space Systems

The Marshall Space Flight Center is actively involved in the area of large space systems (Fig. 23). Studies are already in process on the Science and Applications Space Platform, the Geostationary Platform for Communications, the Satellite Power System and a number of scientific projects requiring construction considerations. Underpinning these systems activities is a strong and comprehensive program looking at the "how" of large space systems including their structures. This program of technology development has been formulated to address in a direct manner the requirements identified by the systems studies while concurrently addressing a number of basic discipline related endeavors. Full advantage is taken of complementary work at other NASA Centers and government agencies.

Modal Control Flight Validation Experiment

The objective of this effort, now under study, is to extend the SEPS Solar Array flight test to include both modal and control validation tests. This flight experiment was defined for the 1984 time frame and will provide needed data on a very timely basis for future

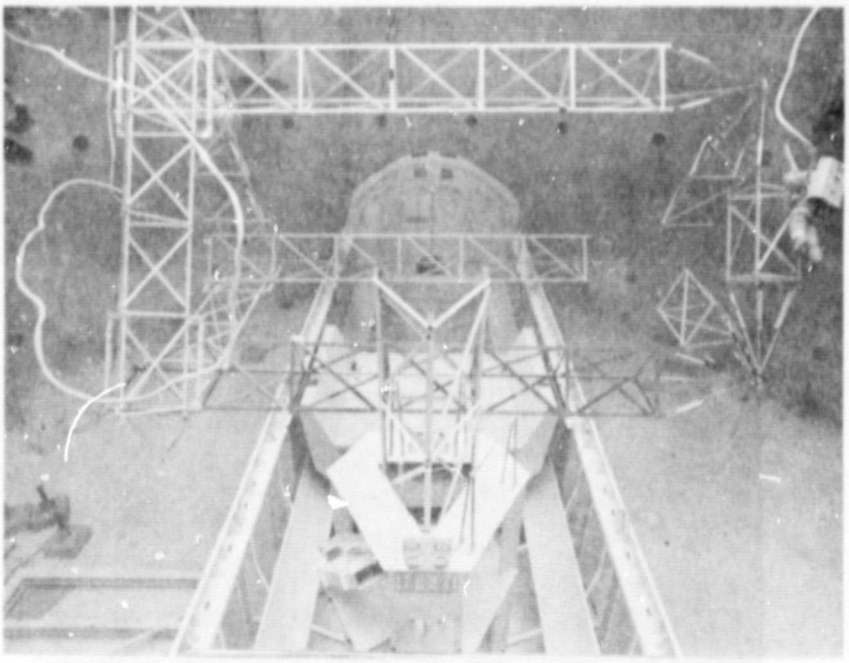

Figure 23. Evaluation of Large Structural Members in the MSFC Neutral Buoyancy Test Facility.

projects. The vibration ground test program of the one meter aluminum beam will serve somewhat as a modal test bed for the design of the experiment.(J.C. Blair/ED01/205-453-2524)

Deployable Platform Activities

Three studies of advanced space systems (the SASP, Geostationary Platform and the SPS) have been completed and are being analyzed for the purpose of identifying technology requirements. These requirements will provide the basis for developing a five year technology program applicable to deployable and possibly other methods of space construction. Ongoing activities include design and fabrication of a deployable module for deployment and assembly verification tests in the MSFC neutral buoyancy facility. Another effort is being carried out to design, fabricate and test a deployable truss for the SASP. Other deployable systems of interest include the design of deployable masts and booms. Preliminary study effort has been initiated. (E.E. Engler/EP13/205-453-3958)

Space Fabrication

The MSFC Beam Builder has been in operation for two years undergoing checkout and evaluation. Beams produced are being used for neutral buoyancy assembly simulations and the one meter beam dynamic and structural test programs. The pierce-and-fold station has been completed and is ready for installation. This station represents a mechanical device for possibly replacing the spot welding subsystem on the Beam Builder. Rather than spot welding, this device pierces a hole through the metal, folding it back on itself making a very strong

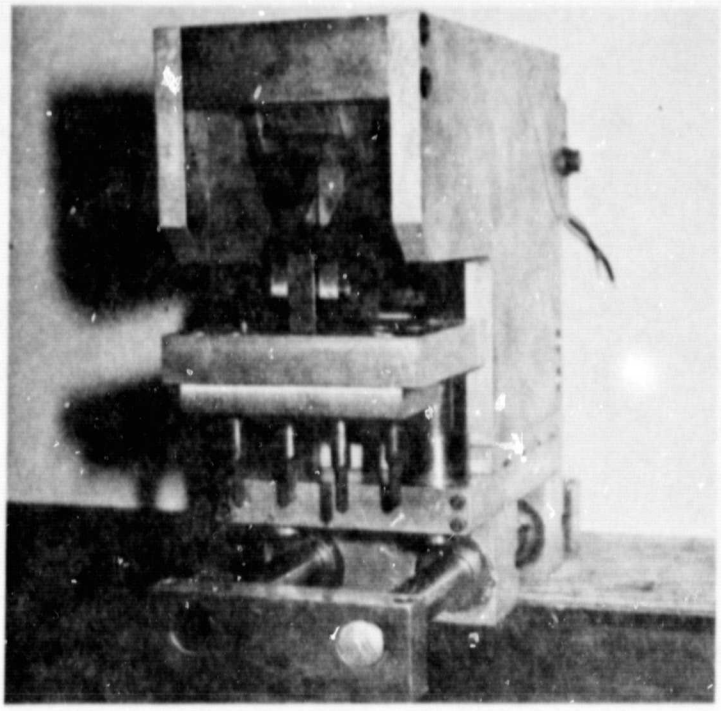

Figure 24. Test Model of Pierce-and-Fold Station for the MSFC Beam Builder.

and reliable joint. If successful, it will significantly reduce weight, electrical power requirements and improve reliability and maintenance. A study is underway to design and develop a composite cap member forming head which is compatible with the existing Beam Builder. The forming of a straight composite longeron for the beam is the pacing technology requirement to realizing an all-up workable composite machine. Bonding of the beam members is under study. A system of induction bonding of the composite elements shows considerable promise.(H.J. Dudley/PS03/205-453-2813)

Attachments for Space Fabricated Beams

The MSFC Beam Builder, a prototype machine for fabricating beams in space, has been demonstrated several times. Attachment devices are required for assembling these beams into large space structures. These attachment devices are of mainly two types; a lap joint and a centroidal joint. The lap joint permits two beams to be lapped across each other and attached. The centroidal joint is a tripod like device which attaches to the ends of each beam and permits several beams to be attached to a common point.

Attachments have been designed, fabricated, and tested for both the lap joint and the centroidal joint in MSFC's Neutral Buoyancy Simulator. These tests have verified the joint concepts and provided timelines for on-orbit assembly. (E.E. Engler/EP13/205-453-3958)

Deployable Antenna Flight Experiment

Study of a flight system configuration was continued during FY80 to define a large-aperature engineering flight test and measurement program in low-Earth orbit on the Shuttle Orbiter. Orbital test configurations were identified to provide technology support for future space applications which utilize large structures deployed directly from the Shuttle or upper stages. The flight system is being configured as a reusable test-bed facility to evaluate structural and electronic characteristics applicable to future civil and military system designs with 50-200 meter apertures. Concept studies during the past year provided expanded analyses and simulations on control dynamics for the Orbiter-attached antenna configuration. The assessments on radio frequency and structural measurements are directly applicable to technology needs for multi-users in areas of communications, radar, and radiometry. (W.E. Thompson/PS04/205-453-2796)

ADVANCED DEVELOPMENT

Programmable Power Processor

A multipurpose electrical power regulator device designed at MSFC has demonstrated its versatility and capability in reducing power processor development time and electrical power system costs. The device, a programmable power processor (P^3), has been tested in a 25 kW power system breadboard. One unit was programmed as solar array peak power tracker/battery charger and a second unit was programmed as a bus voltage regulator/battery discharge limiter. Two additional units were programmed and tested singly and in parallel as a solar array peak power tracker/impedance matching bus regulator in a JSC Power Extension Packager (PEP) breadboard. Typically, a single larger power processor development costs on the order of 2 to 5 million dollars. The test results were quite indicative of the significant cost savings that can be achieved in present and future applications. The P^3 is currently being packaged in a flight configuration and will be subjected to qualification level testing next spring. (J.R. Graves/EC12/205-453-2514)

SEPS Multiphase Power Processor

The Solar Electric Propulsion Stage (SEPS), using mercury bombardment ion thrusters, has been in a research and development stage for well over a decade. The basic characteristics of an ion thruster, i.e., the generation, acceleration, discharge, and neutralization of an ionized gas plasma, requires rather unique power systems. During FY80, MSFC conducted a study to establish the feasibility of a multiphase power processor design for SEPS. The design has inherent redundancy since the failure of any one of the six power sections reduces maximum output power by only one-sixth. In other areas, single failures can be tolerated without adversely affecting system performance. The study shows additional benefits from improved overall efficiency of the power processing system, reduction in weight and parts count of the power processing system, improved reliability of circuit operation, and application of proven electronic parts and components and design techniques. (R.E. Kapustka/EC12/205-453-2510)

Solid Film Lubricants

Solid film lubricants are being evaluated at the Marshall Space Flight Center for use on Space Shuttle structural bearings and various other applications on ET, SRB, Orbiter, and SSME. Loads and environmental requirements for the Space Shuttle applications are unique and very stringent. First, space environment dictates that the lubricant must endure space vacuum without excessive outgassing; second, liquid hydrogen used for propellant is -423°F thus very low temperature must not adversely affect the lubricant; and third, very high stress up to 200,000 psi must not cause the lubricant to break down.

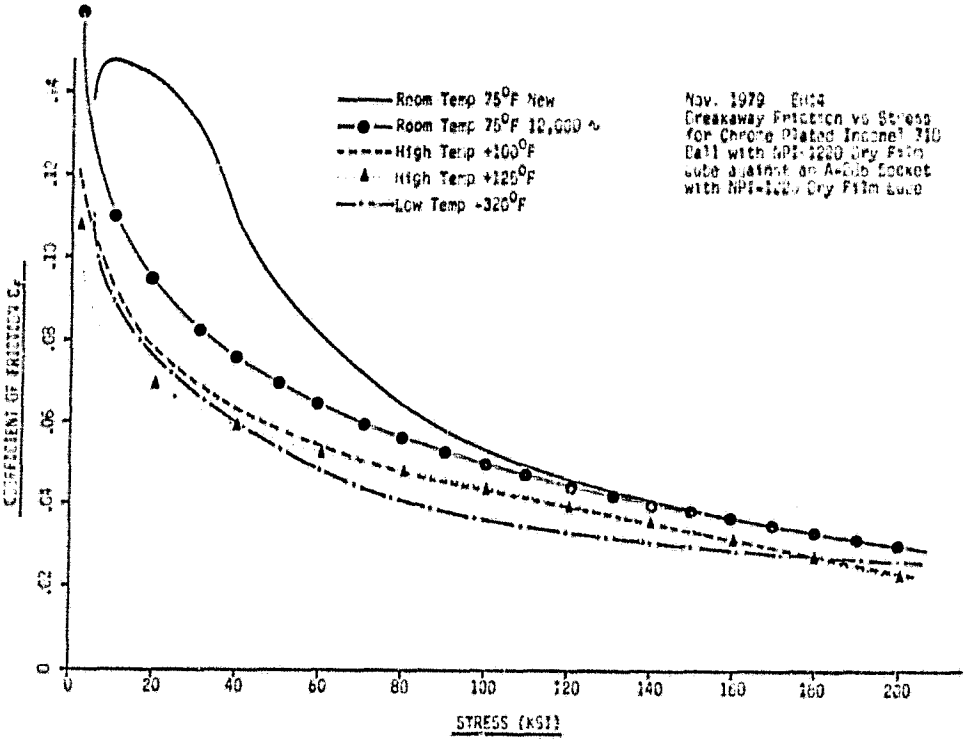

Figure 25. Coefficient of Friction as a Function of Stress for a Dry Film Solid Lubricant.

A ceramic bonded dry film lubricant has proven most successful in meeting most of the application requirements for the Space Shuttle. Figure 25 depicts coefficient of friction value as affected by stress and temperature. Work is continuing to broaden the spectrum of dry film lubricants as they prove applicable to space uses. (F.J. Dolan/ EH14/205-453-1504)

Robotics Utilization in Shuttle Insulation Development

Marshall Space Flight Center is advancing the current state-of-the-art in the utilization of Robotics to improve manufacturing techniques associated with Shuttle hardware production. Engineers at the Center are integrating robotics into total computer controlled systems designed to advance process engineering technology to meet high launch rate fabrication and refurbishment requirements of recovered Shuttle hardware. Marshall engineers are expanding the control capability of

the robot with the addition of a master computer which extends the robots flexibility and allows it to perform in consonance with other major production equipment which is also automatically controlled by computer programming.

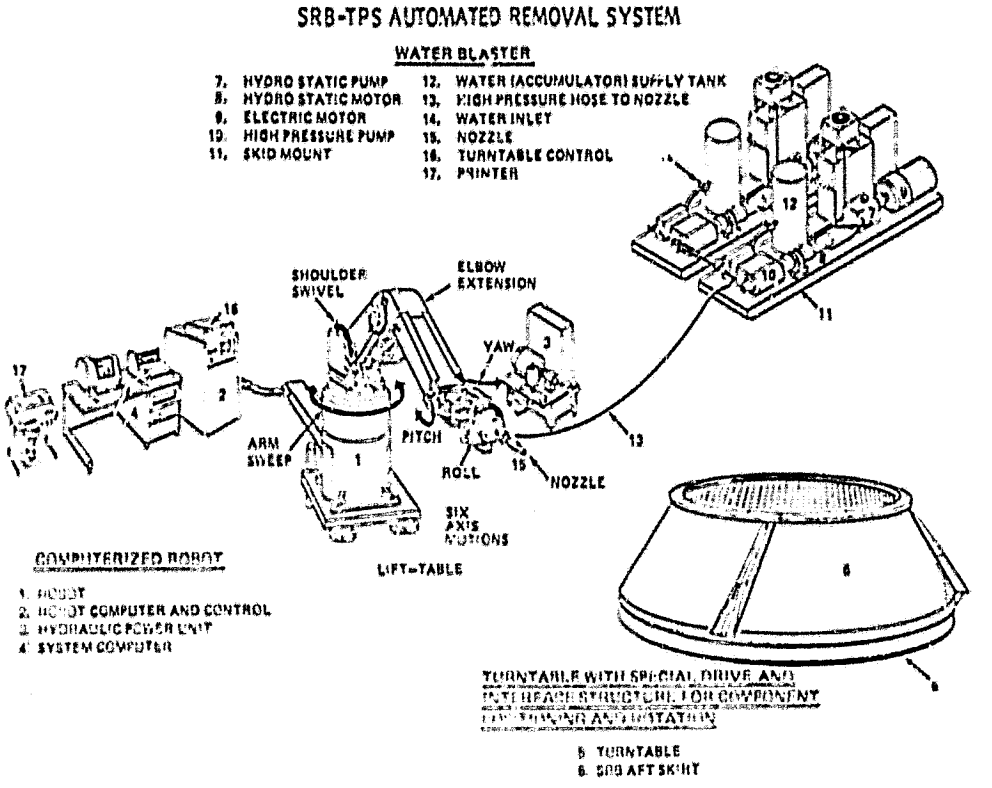

Figure 26. Cincinnati Millicron T-3 Robot Application For Automated TPS Removal.

Two robots are installed at MSFC, and are currently operational. One of these is part of an automated process developed for spray application of the thermal protection system to Shuttle Booster hardware. This utilization of robotics at MSFC is specifically directed toward development of a similar automated process system at KSC. The second operational robot will be integrated with specialized equipment currently being installed at MSFC to advance materials and processing technology unique to the thermal protection system of the External Tank (ET). Computer controlled robotics and a computerized data acquisition and process monitoring system plays a major role in the overall ET TPS development capability. A third highly sophisticated computer controlled unit now being procured is a robot-manipulated high-pressure water blast designed to automate the removal of spent insulation from recovered SRB hardware. (C.H. Jackson/EH43/205-453-0643)

Continuous Forming of Composite Beam Caps for Large Space Structures

Automated fabrication of composite structural elements while in Earth orbit has been proposed as an efficient process for providing on-site sub-components for assembly of large space structures. Pultrusion, a continuous forming and curing process by which fiber-reinforc-

ed polymeric materials are transformed into effective structural shapes, has been refined to meet the interface requirements of an existing laboratory beam fabrication machine. Manufacturing feasibility for production of very thin-walled, multi-plied beam caps has been demonstrated. On-going work will result in demonstration of automated processes for folding, forming, and densification of pre-consolidated multi-layer tapes into extremely rigid, thermally-stable composite beam caps. Closed, triangular caps will be produced with multiple layers of precisely-oriented graphite fibers bound with both thermoset and thermo-plastic resin systems. (H.M. Walker/EH43/205-453-0643)

Shuttle Solid Rocket Motor Nozzle Alternate Ablative Evaluation

The present Shuttle Solid Rocket Motor (SRM) nozzle utilizes a single source continuous filament rayon precursor type carbon ablative. Approximately 12 to 13 thousand pounds of carbon phenolic raw material is required to fabricate each nozzle. Concern about the availability of the baseline ablative due to the possibility of continued reduction in the production of continuous filament rayon and about its recent increasing cost indications has stimulated interest in alternate fibers. Several promising alternate ablatives have recently become available. A limited subscale nozzle test program was initiated to evaluate ablatives which utilize polyacrylonitrile (PAN), pitch, and staple rayon fibrous precursors.

A four-inch throat diameter, submerged test nozzle was designed to evaluate the candidate ablative performance in a simulated Shuttle nozzle environment. A 48-inch diameter char motor with a 3200 lb. cartridge-loaded propellant grain was used in this evaluation. The Shuttle propellant formulation was used with a slight burn rate modification to achieve the desired pressure-time history (average chamber pressure 750 psia and burn time 50 sec. selected and achieved).

Test results indicate that several pitch and PAN based carbon phenolic and graphite phenolic ablatives are equivalent or superior to the present baseline ablative. The availability and cost of the new ablatives also appear equal or superior to the baseline. Six ablatives demonstrated a significant performance increase in these limited tests.

An AIAA paper was presented at the June 1980 Joint Propulsion Conference by MSFC, detailing the results of this evaluation (AIAA-80-1102 Shuttle Subscale Ablative Nozzle Tests, L.B. Powers NASA/MSFC and R. L. Bailey, JPL). (L.B. Powers/EP25/205-453-3809)

Second Generation Sprayable Ablator Development for Shuttle Solid Rocket Booster

A low denisty (18-20 pounds/ft^3) sprayable ablator is under development for the SRB elements to provide thermal protection during ascent and reentry. The currently applied ablator, MSA-1, is limited to application thicknesses of 1/8-inch. The formulation under development is targeted for 1/2-inch spray application and adequate thermal performance to be used on the SRB aft skirt as well as forward elements. Various binders such as epoxy-novolac, epoxy-polysulfide, and

rubber-modified epoxy have been utilized together with micro- balloon and glass fillers to produce candidate sprayable formulations, using methylene chloride/perchloroethylene as a carrier. Cured candidate ablator formulations in one-half inch thicknesses have been produced, but cracking following curing frequently occurs. A detailed processing matrix of layered application sequences as well as pre-cure and cure time/temperature are currently being investigated to control cracking. (W.J. Patterson/EH33/205-453-3536)

Dynamics of Cavitating Cascades

At the conclusion of the Saturn program, it was evident that simple Inductance-Resistance-Capacitance (L-R-C) models of turbopump dynamics as used in space vehicle POGO model were inadequate. For this reason, an extensive analytical and experimental study of cavitating pump dynamics was undertaken. This work has resulted in significant advances in the understanding of cavitating pump dynamics as evidenced in the receipt by the researchers of the American Society of Mechanical Engineers Robert T. Knapp Award.

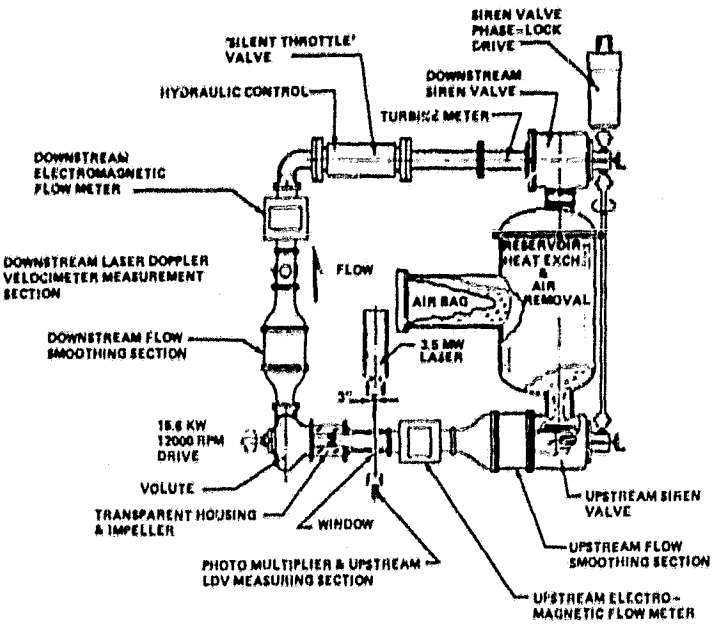

Figure 27. SSME Modified Dynamic Pump Test Facility.

Experimental transfer functions of a cavitating pump inducer (Fig. 27) were measured; this was a significant accomplisment in that it required the development of a means for measuring dynamic flow. The following facts were found: (1) The non-cavitating results departed from quasi-static analyses for reduced frequencies > 0.3; (2) with modest amounts of cavitation, the characteristics became quite complex and none of the elements could be disregarded; and (3) the pump inducer becomes an increasingly "active" device as cavitation number is reduced.

A bubbly flow model was developed to describe the inducer dynamics. It yielded transfer functions which, when plotted, showed proper trends and were in fair quantitative agreement with the experimental data. The results of these studies have been of considerable interest outside the aerospace field, especially in the nuclear power industry for use in "loss of coolant accident," studies. The results have provided greatly improved confidence in the engine dynamics data used in the Space Shuttle POGO analyses. (L.A. Gross/EP23/205-453-3812)

Deep Cavitation Performance of Propellant Pumps

In developing a satisfactory shutdown sequence for the Space Shuttle Main Engine, it was found that the oxidizer pumps would be forced to operate at low and no-flow condition with no net positive suction head (NPSH) while significant power was still being applied to the pumps. This resulted in a potentially hazardous shutdown condition. A review of the literature found no references to this type of operation. The experimental apparatus, as shown conceptually in Figure 28, was used to obtain the required data by extensive testing of the Space Shuttle Main Engine oxidizer pumps.

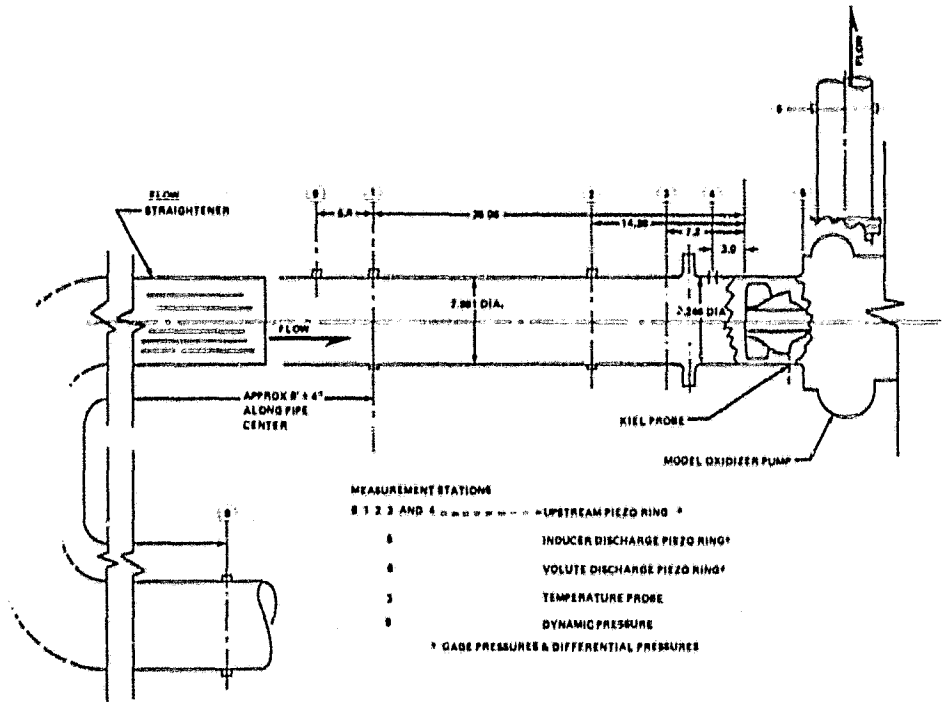

Figure 28. SSME Model Pump Test Facility.

Developed heat and torque data were taken over a range of flows from design flow to zero flow and over a range of NPSH from non-cavitating to zero. In addition, inlet and discharge velocity, temperature and pressure survey data were obtained. It was found that

the developed head and absorbed power went to zero as the NPSH approached zero. It was also observed that NPSH definition became critical because of backflow and temperature rise considerations. These data allowed a comprehensive flight shutdown model to be developed for Space Shuttle Main Engine. (L.A. Gross/EP23/205-453-3812)

Cryogenic Management Breadboard

Cryogenic propellants are frequently considered for advanced orbital transfer vehicles. However, the development of a reduced gravity cryogenic management system involves the integration of multiple technology areas, some of which are relatively unexplorerd. Typical elements of a cryogenic management system are a reusable multilayer insulation, insulation purge bag system, zero-gravity thermodynamic unit, destratification mixer, pressurization provisions, capillary acquisition device for engine restart propellants, and a pump feed system. Integrated system level testing/experience is virtually nonexistent on such a system. Therefore, the design for a large scale test article (87-inch diameter) which contains all the basic elements of a cryogenic management system has been accomplished. The cryogenic management breadboard test article, designed for normal gravity testing, is illustrated in the Figure 29.

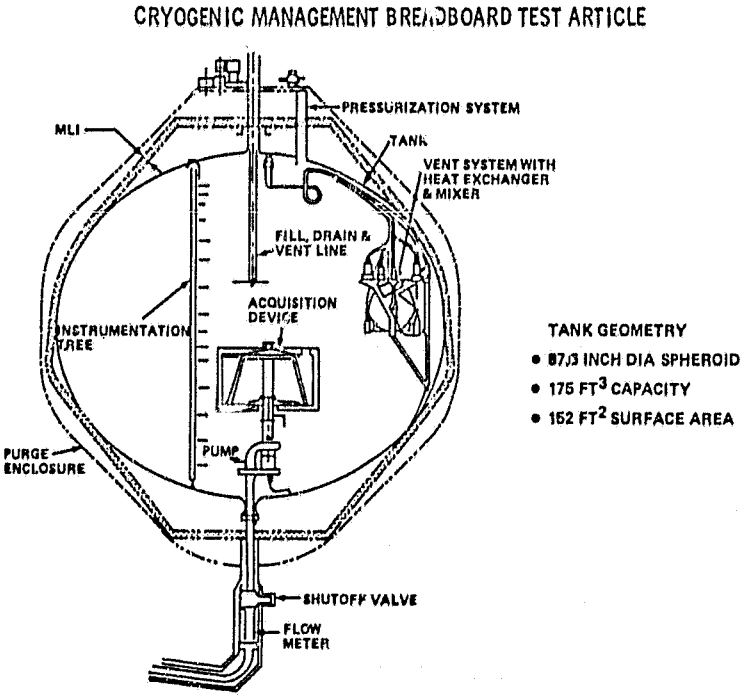

Figure 29. Cryogenic Management Breadboard.

As a part of the cryogenic breadboard effort, a low cost multilayer insulation alternative to goldized kapton has been developed. The new insulation is organically coated aluminized Kapton which currently costs $\$2.80/ft^2$ compared to $\$36/ft^2$ for goldized Kapton.

Therefore, a cost reduction of $830K per vehicle is achieved on a representative orbital transfer vehicle. Insulation blankets using the new material have been fabricated for the breadboard test article. Also, considerable emphasis has been placed on the development/design of the capillary acquisition device for the breadboard since capillary acquisition is a weak technology area. Analytical relations describing the fluid flow/capillary retention characteristics of a capillary device have been developed and the design of a 3.4 ft^3 unit is complete. Other breadboard components are available for reassembly of the test article. (L.J. Hastings/EP43/205-453-3625)

Induced Environment Contamination Monitor

The Induced Environment Contamination Monitor (IECM) was prepared and delivered to KSC for flights on the first Shuttle mission. The IECM consists of 10 separate instruments integrated into a self-contained package. The instruments are: Humidity Monitor, Hygrometer, Air Sampler, Cascade Impactor, Passive Sample Array, Optical Effects Module, Temperature-Controlled Quartz Crystal Microbalance, Cryogenic Quartz Crystal Microbalance, Camera/Photometer, and Mass Spectrometer. Figure 30 shows the placement of these instruments with the exception of the Humidity Monitor and Hydrometer, which are actually part of the Air Sampling System and are not visible in the figure. The IECM is scheduled to fly on the first four Space Shuttle flights and on Spacelabs 1 and 2.

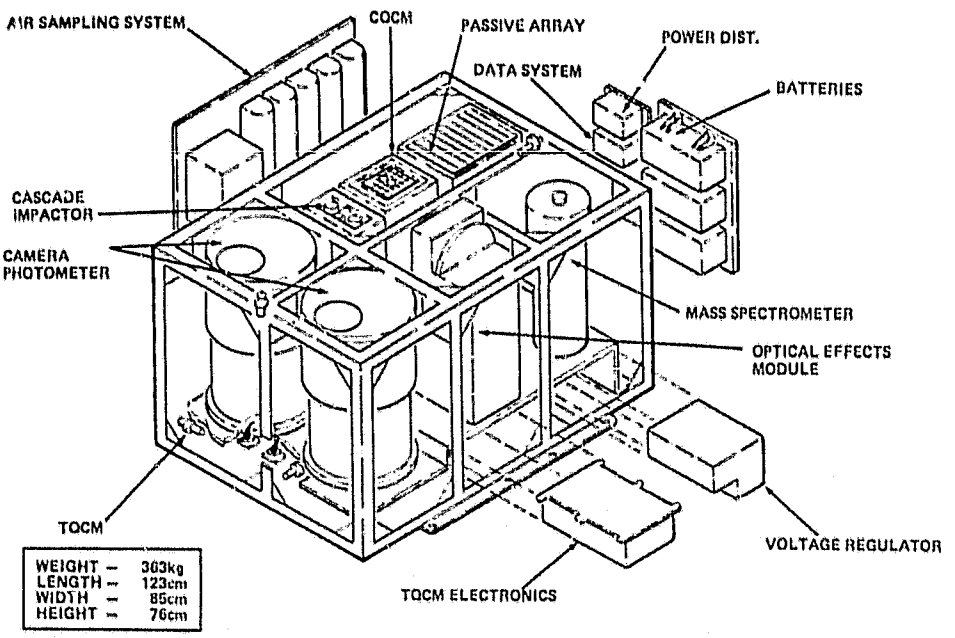

Figure 30. Induced Environment Contamination Monitor (OFT/DFI and Spacelab VFI Unit).

With the IECM instrumentation, contaminants can be analyzed, and contaminant sources may be identified and eliminated. The IECM will also provide data on the interaction of the induced and natural environments and will proide critical data for planning of future Space Shuttle payloads. (E.R. Miller/ES64/205-453-5130)

Automatic Docking Schemes

The retrieval of payloads in space by small, highly maneuverable propulsive stages is greatly facilitated by automatic or semi-automatic systems. Such systems can out-perform humans in some tasks. In others, system complexity and communication requirements can be reduced by assigning most of the task to an autopilot. An automatic docking scheme, in which the target vehicle is entirely passive and may be tumbling, has been developed and tested in an all-digital, 2-body simulation program. Two schemes for sensing relative motion have been devised. One utilizes a laser ranging device, while the other uses a pattern recognition system. Relative position between vehicles and relative attitude information are then extracted from the device output, using stochastic methods. Applying phase plane control logic to the attitude and position errors that are obtained, engine firing commands are generated and multi-axis control is achieved. An inherent feature of this type of control scheme is the ability to station-keep at a fixed distance and orientation from a target body. Such a capability is envisioned for future servicing and docking applications. (H.J. Buchannan/ED15/205-453-4582)

MSFC has long been active in technology development activities, particularly in propulsion and power systems. These activities, which also support the missions at other Centers, are of direct benefit to the many and varied missions that are underway or under study at MSFC.

SYSTEMS TECHNOLOGY

Satellite Power System (SPS)

Increased attention is being directed toward using the Sun as a nondepletable energy source. Its energy can be converted to electrical energy and made available for terrestrial usage on a 24 hour basis by a Satellite Power System (SPS) such as shown in Figure 31. NASA and the Department of Energy (DOE) are jointly participating in a program of SPS concept development and evaluation.

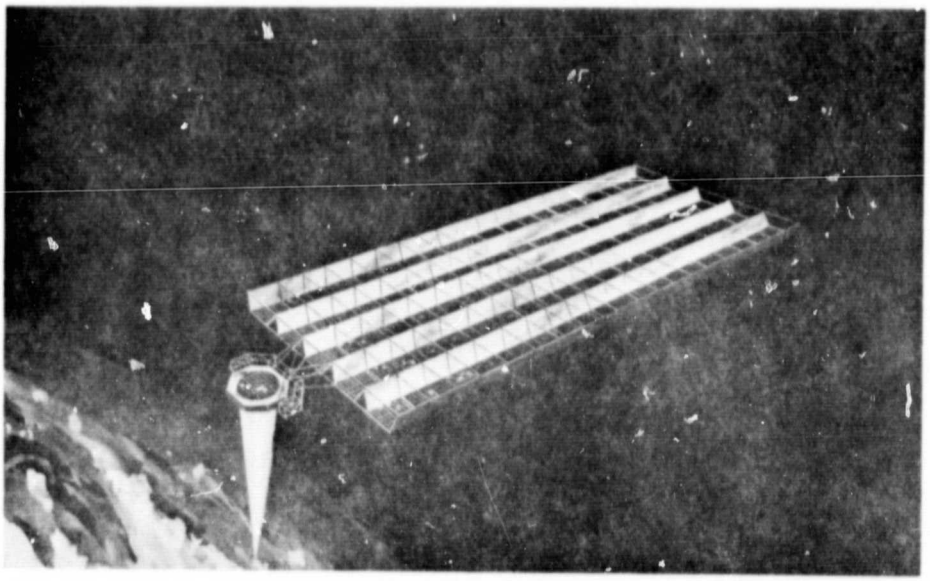

Figure 31. Solar Power System.

During 1980, MSFC investigated and defined alternative system and subsystem concepts. Emphasis centered on a Gallium solar cell-magnetron tube photovoltaic/microwave SPS satellite concept. Conceptual designs developed were compared to the NASA/DOE reference concept (1978) to determine the potential of the new concepts. Critical supporting investigations were initiated in critical areas such as solid state microwave amplifiers, critical materials lifetime assessment, and large structures testing. (C.H. Guttman/PS01/205-453-0162)

Coal Gasification

At the request of the Tennessee Valley Authority (TVA), MSFC initiated a Systems Engineering Support effort to assist TVA during the conceptual design phase of a large commercial coal gasification plant (Fig. 32). In support of this effort MSFC developed an economic analysis model capable of evaluating plant economies and alternate synthetic fuel products. The model that was developed as a result of this effort was utilized to assist TVA in planning the follow-on phase of the project, particularly in areas affecting plant product output and determining economic sensitivity for commercial viability. An effort has also been initiated to investigate Advanced Power Generation Systems Utilizing Coal Derived Fuels. This effort, planned to last six months, will focus on magnetohydrodynamics, fuel cells, and combined cycle gas turbines. (C.H. Rutland/PF15/205-453-1232)

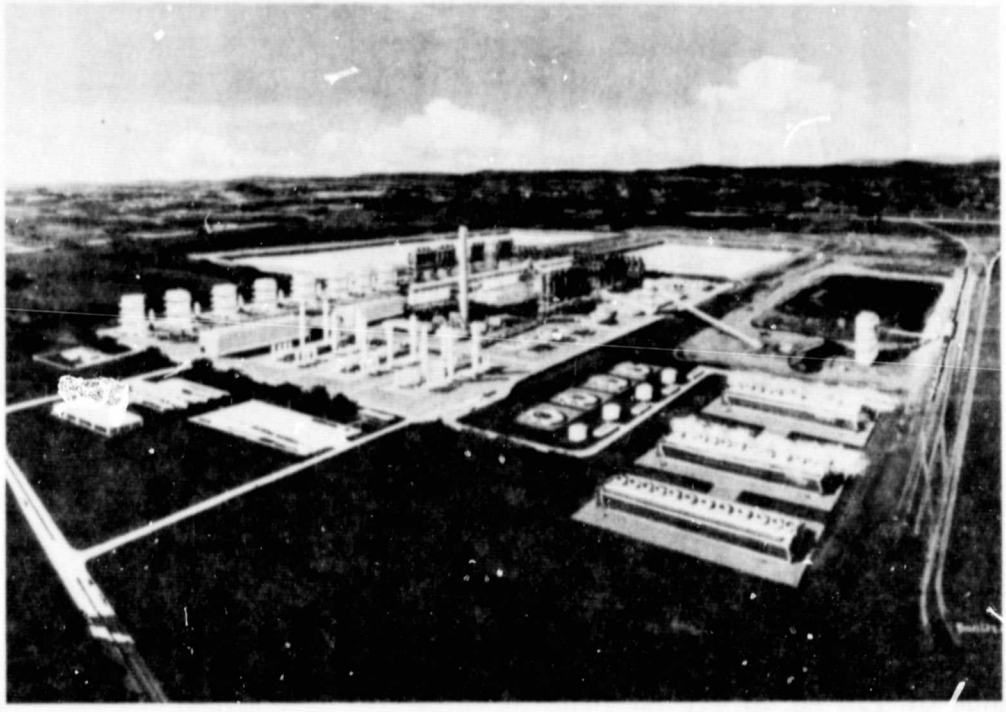

Figure 32. Artist's Rendition of a Coal Gasification Plant.

TECHNOLOGY DEVELOPMENT

Solar Site Test Module

Solar energy demonstration sites utilize permanently mounted sensors and a site data acquisition system to collect data on the system. In many cases, the recorded data must be translated into engineering units for troubleshooting purposes. MSFC has developed a Solar Site Checkout Test Module that can interface with the site data acquisition system to provide the data in engineering units to personnel not fa-

miliar with computers and data systems. The module (Fig. 33) consists of a microcomputer, a cassette recorder, program tape and interface cable. It is small enough to be transported as carry-on luggage. Its simple operation permits analysis and correction of any problems very quickly. (J.M. Price/FA31/205-453-1288)

Figure 33. Solar Site Checkout Test Module.

SEPS Solar Array

A test program of the SEPS Solar Array was conducted which characterized the performance of nine (9) types of solar cells over the range of 1.0 AU to 4.0 AU in both intensity and temperature. A ground test method was also developed and simulated the unfolding and folding characteristics of lightweight solar arrays in a low-gravity environment in support of the SEPS Solar Array Experiment and the Common Solar Array Program. The stiffness capability and hinge designs of the new lightweight solar array panel were demonstrated in a zero-gravity environment in the KC-135 aircraft. The vibrational characteristics of a SEPS type continuous longeron extension mast were demonstrated under simulated zero-gravity conditions at the Lockheed Missiles and Space Company. (L.E. Young/EC12/205-453-2110)

High-Density Electronics and Data Systems

The major factor in the cost of semiconductor parts used in space electronic systems can be attributed to NASA's stringent quality assurance requirements. MSFC has been developing automated fabrication and monitoring equipment which will enable the same level of assurance

to be accomplished at a lower cost through improvement of product uniformity. During FY80, MSFC developed a totally automated resistivity monitor (Fig. 34) including in-line air track load and unload. This unique monitor is now available to industry for use in manufacturing semiconductor parts. The surface contamination monitor, previously

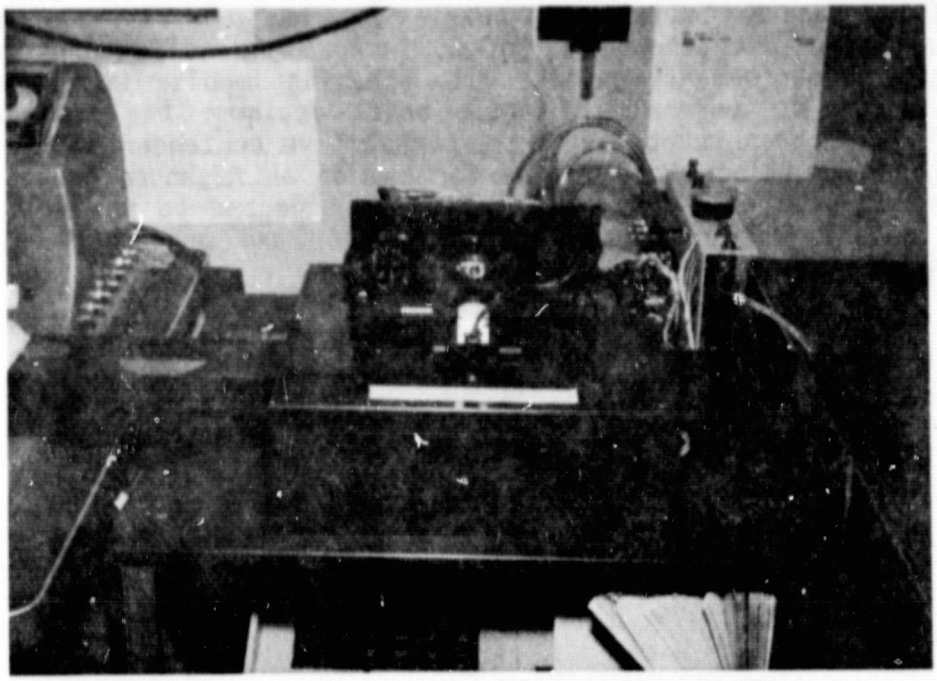

Figure 34. Automated Resistivity Monitor (Cover Removed).

developed by MSFC, has been under intense evaluation by industry during FY80. These developments enhance the U.S. position in the world market for semiconductors and are applicable to computers, hand calculators, electronic watches, and television games, as well as NASA's space vehicle programs and data processing systems. (J.M.Gould/EC45/205-453-3772)

Solid-State Sensor for Stellar Tracking

The Charge Injection Device (CID) is a solid-state sensor capable of detecting low intensity light sources such as stars. It consists of an array of MOS capacitors which can store charge resulting from photon generation due to the light source impinging on them. The sensor, along with the electronics for processing, can be used to measure very accurately the position of a point source within its field of view. Accuracies of one part in 25,000, as opposed to present capability of one part in 5000, appear to be feasible. Compared to the present vacuum tube type sensors, the solid-state device is smaller, uses less power, is more rugged, and requires no high voltage. Recognizing the potential of the CID, MSFC began working with the General Electric Company in 1976 to develop the device for stellar tracking. As a result,a working breadboard solid-state sensor is now available specifically designed for stellar tracking. (C.S. Jones,Jr./EC24/205-453-4268)

Orbit Transfer Vehicle Design

Preliminary point designs have been completed for expander cycle engines applicable to an Advanced Orbit Transfer Vehicle. These designs are for 15000 lb thrust engines using the latest state-of-the-art and expander cycle engine technology. They use liquid hydrogen and liquid oxygen as propellants. Chamber pressures are approximately 1500 psia and extendible bell nozzles provide area ratios of about 600 at a retracted engine length of 60 inches. These features result in very high performance engines with specific impulse in the region of 480 sec. As a result of these point designs, the expander cycle engine has been recognized as a competitive contender along with the staged combustion cycle engine for use on an Advanced Orbit Transfer Vehicle. The expander cycle engine is expected to be very reliable and relatively less expensive to develop and produce.(D.H. Blount/EP24/205-453-4827)

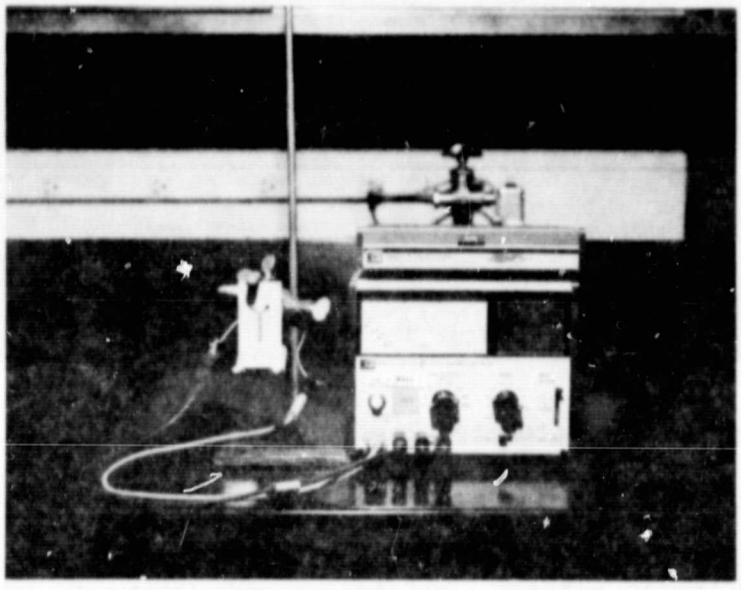

Figure 35. Determination of Insulation Resistance of Urethane Conformal Coating.

Improved Polymers

Polyurethanes are used by NASA for connector potting and circuit board coatings. The excellent dielectric properties of certain of these materials are degraded by high humidity/temperature environments. A study was conducted to develop structure/property correlations to guide development of moisture-resistant urethanes. It was established that urethanes with saturated hydrocarbon structures prepared by the hydrogenation of polybutadiene are hydrolytically stable (Fig. 35). These alkane-based urethanes have excellent dielectric properties and are free of the oxidative instability common to current reversion-resistant urethanes. These urethanes would be well suited for applications in high humidity/temperature environments. (D.E. Morris/EH33/205-453-1221)

Thermal Control Coatings

This project is directed toward development of ladder type methyl silicone resins with reduced methyl group concentration to serve as more UV-resistant and damage-resistant binders for thermal control coatings. Detailed characterization and formulation studies have been performed on the methyl trialkoxysilane hydrolysate as a binder for the thermal control coating. The binder was optimized by varying hydrolysis temperature, time, catalyst type, and water concentration. The candidate coating formulations, based on this binder with TiO2 pigment, were optimized via a detailed series of sprayed test panels that included the parameters of binder/pigment ratio, ethanol content, pigment particle size, coating thickness, and cure conditions. A typical optimized coating (Fig. 36) was prepared by acetic acid cata-

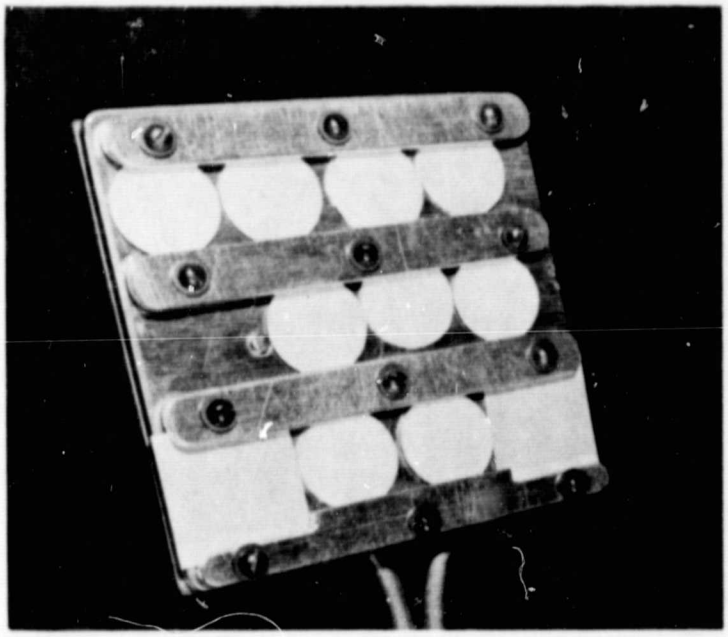

Figure 36. Silane Hydrolysate Thermal Control Coating After 500 Hours Vacuum UV Exposure at One Equivalent Sun.

lyzed hydrolysis of methyl triethoxysilane with 2.5 mol-equivalents of water over a 24 hour period at room temperature. The resulting hydrolysate was directly mixed with pre-milled TiO2 (12 grams pigment/26 grams binder) to yield a sprayable consistency. Panels were sprayed to result in a nominal cured coating thickness of 2 mils. Cure was affected by air drying for 24 hours at room temperature plus 24 hours at 160°F. These coatings are typically extremely tough and abrasion-resistant, with an absorptance of 0.02 and emittance of 0.89. No significant coating damage was observed in the mandrel bend test, even after exposure to thermal cycling from -160°F to +160°F. Vacuum UV exposure of the coatings for 500 hours at 1 equivalent sun shows no visible degradation. (W.H. Patterson/EH33/205-453-4827)

Organosilicon Polymeric Precursors

This project was directed toward utilization of carbosilane (Si-C) or carbosilazane (Si-N-C) polymers as precursors for high strength, high modulus silicon nitride/silicon carbide fibers. Polymeric silazane materials were prepared from controlled pyrolysis of methyl-tris (methylamino) silane and converted into small diameter fibers up to 10 inches in length. These fibers were subsequently moisture conditioned and pyrolyzed at 1200° to render them non-melting. The pyrolysis process was optimized and the fibers were characterized (Fig. 37). Tested fibers have yielded tensile modulus of 29 x 10^6 psi and tensile strength of 100 x 10^3 psi.
(J.M. Clemons/EH33/205-453-3539)

Figure 37. Testing $Si_xN_yC_z$ High Strength Fibers.

Research activities include both atmospheric processes and materials processing in space. The former has long been an active area at MSFC; the latter began with the Skylab program, although the Center has long been involved in materials programs in the laboratories. Both research programs are soundly organized, with active ground-based and flight experimentation programs in progress.

ATMOSPHERIC SCIENCES

Research activities were directed toward producing a better understanding of the atmospherical processes. Studies involved satellite sensor system definitions, utilization of data acquired through correlative field experiments and laboratory research, development of Shuttle/Spacelab experiments, and the acquisition of new knowledge on the thermodynamic and kinematic properties of the atmosphere.

Mesoscale Research Program

The Mesoscale Research Program is an applied research and development program that uses space-related techniques and observations to improve the understanding and predictive capability of mesoscale weather systems, such as severe thunderstorms and tornadoes, flash floods, hurricanes, and cyclones. The cornerstone of the research program is an improvement in fundamental understanding of mesoscale phenomena in the atmosphere. The results are used to understand the capabilities of satellite sensor measurements and their application to operational data. The requirement to use results from the research program in operational meteorology directs the effort in a mission-oriented manner.

Extensive analysis of weather conditions prior to and during severe storm outbreaks, such as the Red River Valley tornado outbreak of April 10-11, 1979 (58 persons killed, 1000 injured), has provided additional information on the mechanisms associated with the formation and development of severe tornadic thunderstorms. These results were made possible by special space and conventional observations acquired by MSFC during the storm periods. Specific analysis efforts included: (1) the determination of mesoscale environmental conditions associated with severe storms, (2) storm environment energetics, (3) influence of jet streams on storm initiation, (4) numerical simulation of environmental and storm dynamics, and (5) development of a severe-storm and flash-flood data sets from weather radar, rawinsonde and satellite data.

MSFC made several important contributions in technology development and predictive capability for mesoscale atmosphere phenomena. They include the development, operational implementation, and evaluation of an objective technique for predicting conditions conducive to the occurrence of thunderstorm complexes from six to forty-eight hours in advance. The technique is being tested at the National Severe Storms Forecast Center and at the Air Force Severe Weather Forecast Section. Additionally, techniques are being studied which may enable the determination of wind (cloud formation) by more automated computer retrieval schemes than are currently available. These techniques, com-

bined with new space observations, will significantly improve understanding and predictive capability for important weather occurrences. This is evidenced by MSFC's participation in new weather satellite systems, such as the GOES-D sensor sent into geostationary orbit in September 1980. (R.E. Turner/ES84/205-453-3539)

Lightning Research

The MSFC 1980 lightning research program consisted of two major efforts: (1) a study project that addressed the feasibility of developing a satellite lightning sensor system and (2) a field research program with a primary goal of supplying the quantitative data needed for the detailed assessment of the lightning mapper sensor.

Three teams pursued the feasibility study: a science and applications team, an optical team, and a RF team. The science and applications team identified the potential users of lightning data (both scientific and application oriented) and determined the actual measurements they required or desired. The optical and RF teams assessed the feasibility of the remote sensing of lightning from space and determined "best approaches." As a result of these studies, it was determined that, with the present state-of-the-art, optical is preferable to RF sensing. Investigations indicated that an optical sensor in geostationary orbit with the capability of determining the location and intensity of lightning flashes would meet the needs of three-quarters of the user community.

A field program, centered around the NASA U-2 aircraft flying over thunderstorms, has been pursued to provide the quantitative lightning data necessary for continued progress on the conceptional lightning sensor design. During 1980, the first simultaneous above-cloud measurements of lightning-produced electric field changes and optical emissions were made. The U-2 and ground measurements were coordinated to aid in the interpretation of remote-sensored data.

A number of measurements were identified that are essential for the continued progress of the lightning mapper program. Based on this information, a set of new instrumentation is being developed for the 1981 research effort. (G.H. Fichtl/ES82/205-453-0875)

Atmospheric General Circulation Research

Research continued on the design of a spherical experimental model of the large-scale dynamical processes of the Earth's atmosphere to be flown on Spacelab. In the model, known as the Atmospheric General Circulation Experiment (AGCE), gravity will be simulated by a radial dielectric body force. Previous design studies indicated that to achieve wave cyclone (baroclinic) instability, a particularly high value of dielectric constant is required for the test fluid. A systematic study to search for a suitable fluid has been initiated. Previous development work had established the suitability of a photochromic dye technique for the flow measurement and a refraction technique for the temperature measurement. Methods to implement these techniques in spherical geometry have been proposed. In particular, a spherical optical imaging system and a flying spot scanner are being studied.

For quantitative scientific design studies, the previous simplified analytical models must be replaced by computer models based on the full Navier-Stokes equations in spherical geometry. A numerical

modeling program has been started. A recent accomplishment is the computation of basic states using a spherical, two-dimensional, nonlinear, hydrostatic model. The stability of these states will then be examined. A cylindrical, two-dimensional, nonlinear, nonhydrostatic model has also been used to compute basic states. The stability of these states will be checked against known data, and then the model will be converted to spherical geometry. The construction of an exact, three-dimensional model for the AGCE has begun. To link the AGCE work to research in atmospheric dynamics, one of the nation's general circulation models (the spectral model of the National Center for Atmospheric Research) is, as part of this research program, being "stripped down" to the essentials of the AGCE.(O.H. Vaughan, Jr./ES83/205- 453-5218)

Flow Visualization and Velocity Determination in Fluids

In research related to atmospheric general circulation studies, flow visualization techniques were used for velocity determination. One such measurement concept was the investigation of a new method for analyzing turbulent flow processes using a photographic technique. The concept involved seeding a fluid with neutrally buoyant particles that serve as flow tracers, intermittently illuminating the moving fluid and particles with a thin sheet of laser light, and photographically recording the particles as a series of images (spots). Knowing the interval between flashes enables velocity estimation. Averaging over several frames of data yields statistics such as mean velocities and Reynolds shear stresses. Software was developed to analyze the photographic data to obtain velocities, and photographic imagery was processed using a computer-controlled digitizer. A grid turbulence cell was designed and fabricated, and velocity data obtained from the cell and analyzed for mean velocities and Reynolds shear stresses gave accurate results.

Another useful characteristic of the photographic measurement procedure resulted from the study. The Lagrangian viewpoint of fluid mechanics views a fluid as a conglomeration of fluid parcels. This viewpoint is relevant to the subject of turbulent diffusion. Because the tracer particles move with the fluid, Lagrangian statistics can be obtained directly from the particle imagery.

The Laser Beam Manifold (LBM) is a direct result of the flow visualization investigation (Fig. 38). The LBM is a device to divide a single laser beam into several beams. It can be designed to make the output beams in any desirable intensity pattern.

Another velocity measurement scheme using higher particle densities and shorter flash intervals was developed. When interrogated with a laser beam, the photographic negative yields Young's fringes from which velocity magnitudes and directions are determined. This technique involved point-to-point interrogation of the photographic negative and yielded precise results. A less precise technique uses optical filtering, interrogates the entire frame at once, and produces an isotach map. (W.W. Fowlis/ES82/205-453-2047)

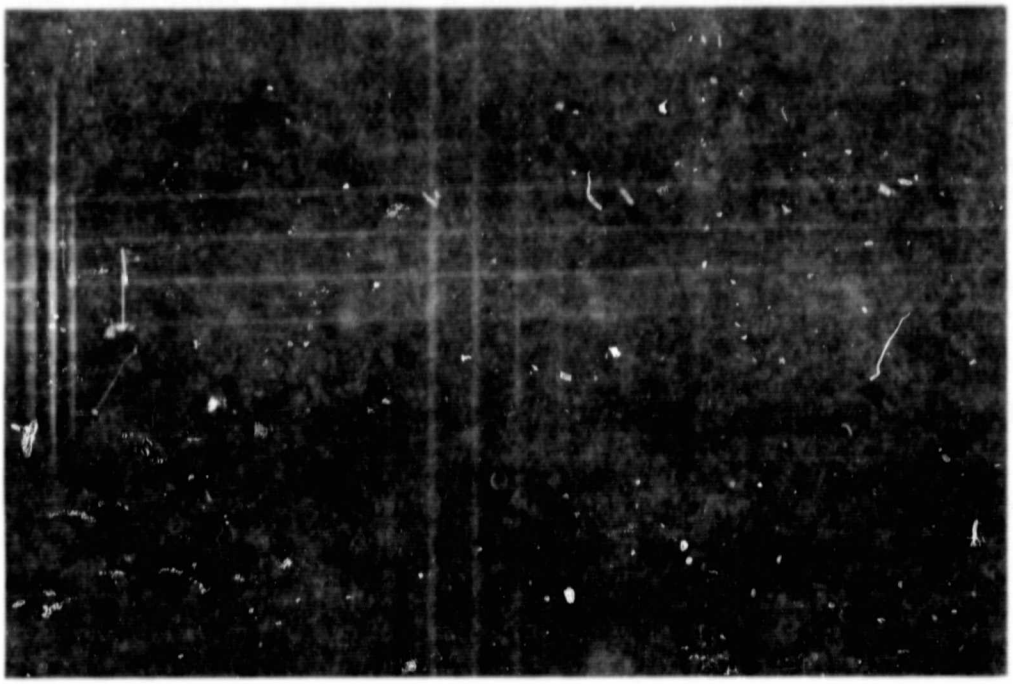

Figure 38. LBM Grid in Tap Water.

Cloud Physics

Experimentation in the low gravity environment provided by the NASA KC-135 aircraft parabolic flights is playing an increasingly important role in MSFC's cloud physics research program. During 1980, an experiment to study the role of convection on ice crystal growth from the liquid was successfully reflown twice, and two new experiments were built and flown. One of the new experiments was a simple, exploratory test to provide an indication of the turbulence levels and decay rates during a variety of cloud physics experimental operations (chamber flushing, expansion, changes of thermal profile, etc.). The second new experiment was a precursor for a potential new research effort to utilize the "thermal wave" concept to study cloud formation and aerosol scavenging physics (Fig. 39). The first flight provided a qualitative verification of the computer model of this process, developed previously under the Atmospheric Cloud Physics Laboratory program, as well as much needed insight into the mechanics of operating the apparatus in low gravity. The system can now be upgraded with the addition of aerosol generation and shaping equipment and refined optics to provide quantitative data. (R.E. Smith/ES81/453-3101)

Atmospheric Variability Experiment

MSFC participated with its Atmospheric Variability Experiment (AVE) in a large interagency mesoscale and severe storms experiment known as AVE-SESAME '79 (Atmospheric Variability Experiment-Severe Environmental Storms and Mesoscale Experiment 1979). A primary objective was to acquire carefully edited sets of rawinsonde data during

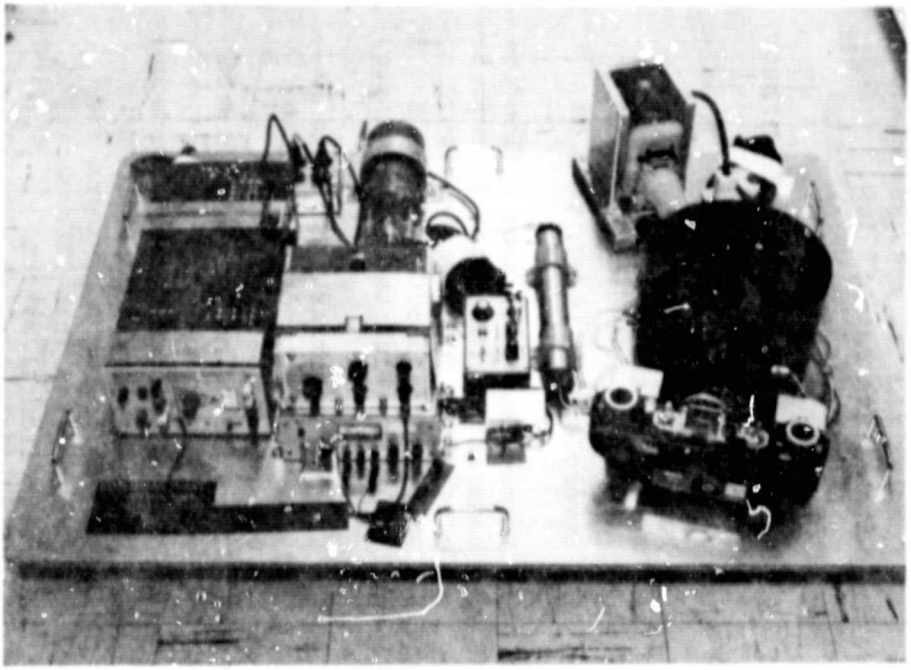

Figure 39. "Thermal Wave" Experiment Hardware.

selected severe weather events for use in correlative and diagnostic studies with satellite and radar data obtained at approximately the same times. Data were acquired during six individual 24-hour experiments on both the regional and storm scales over a network in the central United States that utilized approximately 20 supplemental rawinsonde sites meshed among 23 standard National Weather Service sites.

The new AVE-SESAME '79 data contain higher spatial and/or temporal resolution than most prior AVE data sets and will be used to examine the fundamental mesosynoptic processes responsible for the formation and development of severe convective activity associated with phenomena, such as tornadoes, damaging winds, hail, floods, turbulence, etc., that affect property and personal safety. Another objective is to compile a data set for investigating atmospheric variability and associated severe storm development with emphasis on the determination of mechanisms for the formation and prediction of severe storms. A summary of all MSFC AVE experiments is shown in Figure 40. (R.E. Turner/ES84/205-453-4175)

Ionosphere-Severe Storms Coupling

An isolated tornado in north central Oklahoma on May 29, 1977 was studied extensively. Gravity waves typically observed to occur in the ionosphere just prior to the observation of a tornado were traced to a single cloud in Oklahoma. This cloud was then analyzed in detail using GOES infrared data. This analysis showed that the tornado-producing cloud had a much colder temperature and, therefore, probably higher altitude, as well as a significantly higher rate of vertical growth than any other clouds in the United States. Approximately 30 minutes prior to the touchdown of the tornado, this very high, cold cloud turret suddenly collapsed. Additional cases are being studied to confirm these results. (G.H. Fichtl/ES82/205-453-0875)

Experiment	Dates	Experiment Size & Location	Significant Meteorological Conditions
AVE 1	19-23 Feb '64	31 sites in 18 Central & Southern States	Cyclonic development over the Gulf of Mexico.
AVE 2	11-12 May '74	54 sites encompassing all states east of the Rocky Mts.	Complex frontal sys. associated with active cut-off low.
AVE 3	6-7 Feb '75	41 sites covering most states east of Rocky Mts.	Polar air mass outbreak in MS & OH Valleys.
AVE 4	24-25 Apr '75	Same as AVE 3	Major tornado outbreak in MO & OK
AVSSE 1	27-28 Apr '75	24 sites in 13 Southern & Central States	Tornadoes in NE & OK.
AVSSE 2	6-7 May '75	Almost same as AVSSE 1	Tornado in Omaha, NE
AVE 5	11-12 Jun '76	23 sites in 15 N. Central States	Tornadoes & other severe storms in ND & SD
AVE 6	27-28 May '77	22 sites in Central & Midwestern States.	Severe storms in MO, TN & OK
AVE 7	2-3 May '78	Same as AVE 6	Tornadoes, hail, snow & flooding associated with strong disturbance aloft over Southern Rockies.
AVE-SESAME 1	10-11 Apr '79	23 NWS Stations with 20 supplemental sites enmeshed in 14 states in Central U. S.	Major tornado outbreak in TX & OK including Wichita Falls tornado.
AVE-SESAME 2	19-20 Apr '79	Same as AVE-SESAME 1	Tornado outbreak from ND to TX.
AVE-SESAME 3	25-26 Apr '79	Same as AVE-SESAME 1	Widespread thunderstorms over Midwest & South.
AVE-SESAME 4	9-10 May '79	23 NWS Stations in 14 Central States with 20 supplemental sites in OK	Tornadoes & hail in TX, OK & KS
AVE-SESAME 5	20-21 May '79	Same as AVE-SESAME 4	Severe thunderstorms & tornadoes from the Applachians to OK
AVE-SESAME 6	7-8 Jun '79	Same as AVE-SESAME 4	Widespread thunderstorms from Great Lakes into TX associated with frontal system.
AVE-VAS 1,2,3	Mar-May '81	23 NWS Stations in 16 states, 12 MSFC mesoscale sites in TX & all NSSL observations.	Observations to be made on one clear & two storm days.

Figure 40. Summary of NASA's Atmospheric Variability Experiments (AVE).

Global Weather Satellite Studies

The advent of operational satellites with their unique ability to sense on a continuous basis global cloud patterns and water vapor distributions makes possible an assessment of latent heat on mid-latitude cyclonic systems . MSFC is currently involved in joint efforts with Pennsylvania State University and Purdue University to exploit this technology via combined observational and theoretical procedures. The research consists of two parts. First, temporal and spatial distributions of heating and cooling resulting from condensation of water vapor and evaporation of liquid water from solar and infrared radiation are calculated for selected cyclonic systems over North America using satellite photographs to delineate cloud regions, conventional synoptic-scale observations, and precipitation measurements. Second, the role of heating and cooling resulting from latent heat and radiation effects in the dynamics and evaluation of cyclonic systems is analyzed by first calculating the vertical motion field of the atmosphere and then calculating vorticity and divergence fields and energy budget quantitative like kinetic and available potential energy. Two types of cyclonic systems are being analyzed; namely, systems which are highly stratified with negligible subgrid-scale convection and systems with substantial subgrid-scale convection. The work will lead to new applications techniques of satellite observations of global weather systems and more understanding of cyclonic systems, especially as related to the role of latent heat effects and the importance of subgrid-scale convection on the dynamics and evaluation of these systems. This research will also assist in the development of observational requirements for new satellites, such as the Lower Atmospheric Research Satellite. (G.H. Fichtl/ES82/205/453-0875)

Frost Accretion and Dissipation on an Airfoil

In an effort to enhance safety and in the interest of economy, MSFC is conducting a program to assess aerodynamic lift and drag penalties associated with frost on an airfoil. Frost formation on an aircraft is a serious problem to all segments of aviation. For the air carriers, the Federal Air Regulations requirement for frost removal prior to takeoff is an expensive and time-consuming operation. For general aviation, takeoff with a frost coating is a safety hazard. The National Transportation Safety Board records indicate numerous general aviation accidents which can be attributed to aerodynamic penalties associated with frost on an airfoil.

Computer programs are being developed to model frost formation by numerically solving the heat and mass transfer equations for an airfoil under conditions of natural and forced convection. This model, which is presently being evaluated and modified as appropriate, will provide a useful tool for predicting frost severity under anticipated nighttime atmospheric conditions the evening prior to an actual frost accumulation. Atmospheric data necessary to continue the evaluation of the model will be collected in the winter of 1980. (B.J. Anderson/ES83/205-453-5218)

Warm Fog Dispersal Program

The NASA/MSFC aviation meteorology research effort relative to warm fog dispersal is continuing. At its inception in 1978, this effort was a feasibility and assessment study concerning the potential

of using charged particles for the dispersal of warm fog at airports. The original effort illustrated that some detailed work was needed on certain aspects of a charged particle system. An investigation of some of these aspects was undertaken in 1979; namely, a nozzle to discharge the charged particles, charge transfer to the particles, and particle mobility. It has become apparent that the charged particle system could be a viable system to disperse fog at an airport. The 1980 research effort was concerned with constructing a prototype system, making some system parameter measurements, and making the initial analysis of these measurements.

MATERIALS PROCESSING IN SPACE

This program demonstrates the advantages of using space in controlling processes and in investigating phenomena in ways not possible on Earth. The goals are (1) to stimulate the scientific community, other Government agencies, and industry to use this capability for their own respective interests; and (2) to encourage industry to develop space processing as a commercially viable resource for investigating process control, producing better materials than can be produced on Earth, and for manufacturing limited quantities of materials with extremely high intrinsic value.

Crystal Growth

Various studies are being conducted to determine the effects and limitations imposed by gravity on crystal growth processes. Diffusion coefficients and binary phase diagrams have been measured for HgCdTe and PbSnTe. Work is in progress to determine the ternary phase diagram and to measure the thermal conductivities in the melt. These parameters are important in finalizing the thermal design of the experiments to be conducted in the Solidification Experiments System in the Shuttle.

Detailed thermal analyses of Bridgman-Stockbarger growth have been completed. It appears that the most important factors in obtaining maximum gradients and flat solidification isotherms are the matching of the Biot numbers (heat transfer coefficient divided by sample conductivity) in the hot and cold zones and the control of the cold temperature such that the solidus temperature is the average of the hot and cold zone temperatures weighted by the sample conductivity.

The use of a small booster or tickler heater at the end of the hot zone was found to be of marginal value in increasing the axial gradient at the solidification interface. The use of an adiabatic zone was found to be beneficial in reducing the curvature of the isotherms in the vicinity of the solidification interface with a minimum sacrifice in axial growth.

The growth and stability of solid solution alloy semiconductors have been analyzed during transient and steady state conditions. This is an extension of the classical Smith, Tiller, Rutter analysis of dopant distributions of alloys in which the dopant approaches 50 percent. The analysis accounts for varying segregation coefficients typical of real binary systems. Also, the solidus temperature may vary over several hundred degrees in such systems during the transit to steady state conditions (J.C. Horton/ES71/205-453-0940)

The growth of such systems was found to be inherently unstable in a gravity field. If the rejected component is less dense than the bulk melt, the system is subject to thermo-solutal convection. If the rejected component is more dense than the bulk melt, the more dense material will seek the lowest point on the solidification interface, Since the solidus temperature decreases as the concentration of rejected solute increases, the growth rate at the lowest point is further retarded. Thus, any perturbation on the interface will grow and a planar interface cannot be maintained. (J.C. Horton/ES71/205-453-0940)

Solidification

A low-g casting experiment was successfully carried out on SPAR VII. The object of the experiment was to study the microstructure of alloys (Pb-Sn in this case) as a function of gravity level. Earlier SPAR experiments using transparent metal models demonstrated that grain multiplication by dendrite remelting or breakage did not occur in low-g. Experiments in a centrifuge indicated that grain size decreased with acceleration level. As expected, the flight sample exhibited a relative small number of large grains. The dendrite structure is presently being analyzed, but has shown a higher percentage of equiaxed to columnar structure than ground-based specimens.

A directional solidification of MuBi/Bi eutectic was carried out on SPAR VI. One of the surprising results was the fact that the rods were finer, more uniform, and more closely spaced in the flight sample than in the ground control sample processed in a vertical, thermally stable configuration. This would indicate that the convection driven by the radial gradients in the ground control sample plays a role in the solidification of eutectics. Tests of this system in magnetic fields are being conducted to investigate this effect.

A casting furnace has been developed for use in the KC-135 aircraft. This has been used to carry out low-g casting experiments on samples provided by industrial users under a Technical Exchange Agreement between the companies and the government. To date, several alloys and casts iron compositions have been processed and are being analyzed. (L.L. Lacy/ES74/205-453-5135)

Containerless Processing

Three experiments have been flown on SPAR rockets to demonstrate the containerless control of liquid droplets positioned in a three-axis, room temperature acoustic levitator. Drops have been oscillated and rotated by varying the amplitude and phase/of the acoustic drivers. Droplet coalescence has been studied by deploying two droplets and merging them in the acoustic well. Bubble centering, important to the production of glass containment shells for inertial confinement fusion research, has been studied by injecting air into the liquid spheres and then exiciting certain normal modes of oscillation by modulating the sound field.

The problem of concentric spherical shells is being investigated by a series of laboratory experiments utilizing neutral buoyancy tanks and drop tubes backed up by extensive analytical studies. It has been shown, for example, that third harmonic oscillations in a spherical shell produce forces that tend to center the interior bubble causing the shell to become concentric.

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An attempt was made to form a calcia-silica glass using a single-axis acoustic levitation furnace on a SPAR rocket flight . The sample was successfully deployed and captured in the acoustic well at high temperature (1500°C) and the solidified material was in the glassy state. The acoustic levitator has been modified to increase the acoustic field and the experimentation will be continued on the next SPAR flight.

Two types of aerodynamic levitators have been developed. Some success has been obtained in melting and solidifying small glass samples up to 1000°C. Instabilities as the sample melts and deforms are still under investigation to eventually use this technique for screening glass candidates for containerless processing in low-g.

A number of samples have been containerlessly processed in the 34 meter drop tube at MSFC. Nb-Ge alloys have been undercooled substantially below the theoretical Turnbull limit. Unique microstructures were formed in these Nb-Ge samples as evidenced by shifts in the superconducting transition temperature and lattice parameters. However, the formation of the hoped-for A-15 metastable phase has not yet been confirmed.

A variety of samples for various universities and industries have been processed in the MSFC drop tube. The include PdCuSi glassy metals, various superalloys, and silicon spheres for use in low-cost solar cells. (L.L. Lacy/ES74/205-453-5135)

Fluids and Chemistry

In support of the monodispersed latex reactor (MLR) flight experiment, a rotary reactor has been developed in the laboratory to determine the limitations of ground-based techniques for keeping large-sized latex spheres in suspension during the polymerization process.

A special test cell was constructed to investigate the effects of gravity-driven convection in electroplating. The test cell has been flown on the KC-135 aircraft using shadowgraph, schieleren, and interferometry to observe the concentration profiles and convective flows. Considerable flow was observed in normal gravity and during pull-outs on the KC-135 between the low-g trajectories. However, this flow ceased rapidly as the aircraft entered the low-g portion of the trajectory and the convective plume dissipated into diffusion profiles. Considerable experience was gained in these flights in designing and operating sophisticated optical systems under flight conditions. (R.S. Snyder/ES73/205-453-3537)

Bioprocessing

A Joint Endeavor has been negotiated with MDAC, who is working in conjunction with the Ortho Division of Johnson and Johnson to develop and fly electrophoresis device to perform unique separations of pharmaceutical products on a commercial scale. NASA will provide test

specimens for early Shuttle experiments to characterize the separation device and to provide a basis of comparison with the best available ground-based technology.

An exhaustive study of the flow fields in continuous flow electrophoresis devices is nearing completion. It has been found that the primary cause of sample stream meandering, which limits the resolution of such devices, are the very small thermal gradients across the width of the channel. The conventional solution to this problem is to reduce the thickness of the flow channel, but at the expense of increased sample stream distortion because of Pouisselle flow and electroosmotic flow. This has been the conventional approach. An approach developed at MSFC is to use cooling walls with higher thermal conductivity to level out such variations. This has the additional advantage of increasing the amount of power dissipation without creating temperature inversions or excessive sample heating. The ability to use increased power further increases the resolution of the separation process.

A new type of electrophoretic separator using these principals was constructed and is being tested in the laboratory. This device also has a number of other innovative features, such as a new electrode chamber design to improve thermal uniformity, a new type of sample collection system to minimize flow disturbances, and construction that can be fully autoclaved to facilitate sterilization.

A novel recirculating isoelectric focusing separator developed as a breadboard at the University of Arizona for a potential flight experiment has successfully fractionated a number of macromolecules including interferon. Schering Pharmaceutical Company has provided funding for a similar model built to their specifications for separation of interferon.

Two state-of-the-art countercurrent chromatography separators have been provided on loan to MSFC for NIH for evaluation. This process may also benefit from low-gravity. A joint program is being developed with the Center for Disease Control (CDC) to separate megakaryocytes for the study of arteriosclerosis using this technique.
(R.S. Snyder/ES73/205-453-3537)